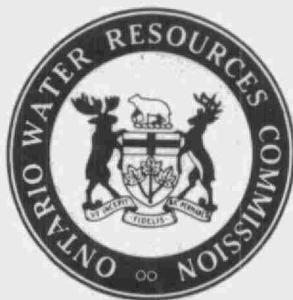


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INDUSTRIAL WASTE

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JUNE 1968

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## PREFACE



D. S. Caverly,  
General Manager,  
Ontario Water Resources Commission,  
Toronto.

Conference Chairman

The 1968 Ontario Industrial Waste Conference, held at the Sheraton Brock Hotel in Niagara Falls, Ontario, was attended by over 300 people. It was agreed by all that this was a most successful conference - not only from the point of view of attendance (the largest to date) but also because of the excellence of the papers which were presented and the amount of discussion which took place both during and after the sessions. May I, on behalf of the Conference Committee, express our sincere appreciation of your participation.

As we become more and more an industrialized society, the necessity of improving our waste treatment methods assumes an ever-increasing measure of importance. It is for this reason that these annual conferences are so important as they provide a forum for the exchange of ideas and provide information concerning new methods of coping with complex industrial waste problems. In its responsibility for water management in Ontario, the Ontario Water Resources Commission is happy to sponsor this annual meeting. It is our sincere hope that you will be able to attend again next year.

If you require information concerning next year's conference, the availability of past Proceedings, or the work of the Ontario Water Resources Commission in general, you are invited to write to us at our offices now located at 135 St. Clair Avenue West, Toronto 7, Ontario.

SESSION CHAIRMAN  
DR. J. D. NORMAN  
ENGINEERING FACULTY  
McMASTER UNIVERSITY



N. L. NEMEROW

"DESIGN AND AGREEMENTS FOR COMBINED TREATMENT  
OF WASTES FROM 22 TANNERIES AND TWO MUNICIPALITIES"

BY

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1. THE PROBLEM

A. General

Cayadutta Creek rises in the central part of Fulton County, New York State, and flows generally south for about 14 miles through the cities of Gloversville and Johnstown and enters the Mohawk River at Fonda (see Fig. 1). The total catchment area covers 62 square miles, above Station No. 6. There are no official gaging stations on this stream, but approximate flow data for a comparatively short time (1898-1900) are available. This creek has been characterized by an expert State Hydrologist, a member of the Geological Survey, as similar to that of Kayaderosseras Creek located in Saratoga County and draining into the Hudson River Basin.

Ninety one percent of the population of Cayadutta Creek is concentrated in the Cities of Johnstown and Gloversville and the Village of Fonda. In 1952 New York State cited this creek as "one of the most grossly polluted streams in the State". From within the City of Gloversville to the junction with the Mohawk River, this stream is entirely unsuited for the support of fish life whereas formerly, this stream was trout water throughout its entire length. It has been stated (by Vrooman in March 10, 1950 Report to City of Gloversville) that the dry weather flow of Cayadutta Creek is higher than the average streams in the state. This is due to the nature of the watershed, the sand soil, and the larger wooded area. He also stated that "the average daily flow of the Creek at the Gloversville sewage treatment plant is 17 million gallons and the low measured dry weather flow is 4.2 million gallons. These were evidently obtained from separate, independent, and unofficial flow measurements.

The Village of Fonda has no sewage treatment plant. However, the creek which has a fall of about 70 feet in the 14-15 mile travel has begun to recover oxygen from Station 6 to the outlet in the Mohawk River (See Fig.1).

\*In 1957, 104 manufacturers were engaged in the production of fabric and leather gloves in Fulton County. It has been estimated that as much as 80% of the fine leathers of America are tanned in Fulton County.

Land for expansion at the present Gloversville Treatment Plant is limited. In addition, built up areas are as close as 500 feet from the plant.

There are about 19 tanneries and 8 other waste contributing manufacturing plants operating within the area of Johnstown-Gloversville. Their wastes are discharged either into the Gloversville sewer and treatment plant before entering Cayadutta Creek (See Fig.1) between Station No. 1 and 3, or enter the Johnstown 30 inch diameter sewer and are discharged

\*City of Gloversville-Community Characteristics, Population Trends Land Use Survey: No date but later than 1959, Russell D. Bailey, Utica, N.Y.



untreated into the creek between Stations 4 and 5 (See Fig.1).

The Mohawk River Drainage Basin Survey Report of the New York State Health Department (May, 1952) recommends an "F" classification (Best usage for discharge of industrial wastes at that time) from Gloversville to Fonda. This class has recently been eliminated from the New York State system. Above Station 1 it is classed C (T).

The tannery industry as a whole is a marginal one, depending primarily upon volume and unique products to show a reasonable profit. The industry is an old one in American history, and has a record of contributing to the serious and damaging pollution of Cayadutta Creek. The National Tanners Association (private communication) estimates that the Fulton County area has been losing about one plant per four years. However, there has been more glove and garment leather demand due to the rising U.S. population. They predict, therefore, that the overall demand for glove and garment leather - produced in Fulton County - will climb slowly upward. This will be accomplished, however, in fewer plants with increased production.

#### B. Specific Situation

The sewage and wastes from the Cities of Gloversville and Johnstown, New York are discharged into Cayadutta Creek which flows from its headwaters in the Southern Adirondacks to the Mohawk River at Fonda, New York, a distance of 14.25 miles. Gloversville had a 1960 population of 21,741 while Johnstown had 10,390. Practically the entire urban population is served by public sewer systems but only half is tributary to a sewage treatment plant. This plant serves the people and industry of Gloversville and consists of a bar screen, grit chamber, 2 antiquated Dortmund type primary settling basins, fixed nozzle trickling filter, one final Dortmund type settling basin and some sludge drying beds. The plant was built in the early 1900's and is incapable of handling more than 1/2 the wastewater of the flow rates presently encountered.

The industry has retained a New York City consulting firm to "represent" its interests in this problem. The two cities have retained a local consulting engineering firm, Vrooman Engineers, who has in turn retained the writer to advise them on study procedures of and solutions to the pollution problem in Cayadutta Creek.

### C. Stream Survey

The Creek was visited and examined at various locations. Dissolved oxygen values were determined in order to locate the sag curve points. After an initial creek appraisal and a trial creek survey, Cayadutta Creek was then sampled at eight appropriate stations shown in Fig. 1. Samples were collected after the first day from stations 1, 5, and 6 only on six days at different times during each day. Composite samples were analyzed for dissolved oxygen, B.O.D. and temperature. In addition, the creek flow was measured on each sampling date at Station 6. The results are shown in Table 1. Flow times are shown in Table 2; a summary of the B.O.D. and flow data shown in Table 3; flow data from a similar gaged creek in Table 4; the probability of the minimum flow data occurring in Table 5; the multiple regression technique analysis of the stream data in Tables 6 and 7.

A stream survey represents an essential part of any well-conceived waste treatment study. Under ideal conditions, the survey designed to study the oxygen sag curve should be carried out during extremely hot weather, extremely low stream flow, and characteristically - high organic matter loading. Seldom is it possible to conduct a stream survey under all of these ideal conditions. In this study, we were particularly fortunate to collect stream samples during extremely low flow conditions comparable to that which may be expected to occur for a seven day period only once in ten years. In addition, municipal and industrial pollution loads were considered to be above average. Although stream temperatures were not very high ( $11^{\circ}$  to  $14^{\circ}\text{C}.$ ), these values may never reach very high levels due to the relatively cold mountain water diluting the wastes. For example, during the State Survey of 1951, samples collected on August 22 and 23 at Stations 5 and 6 showed temperatures of only  $15\text{-}19^{\circ}\text{C}.$

Although the Streeter Phelps method yielded values of  $k_1$  and  $k_2$  which gave a Fair's  $f$  of about 35\*, the results are not dependable because of the variability of wastes from one moment to the next as well as the multiple entrances of wastes into the stream. The only reliable procedure for evaluating the oxygen sag characteristics is to collect many stream samples under these critical conditions and statistically correlate the data in order to obtain a stream equation. This method is commonly referred to as the Churchill Multiple Regression Technique. The stream equation represents the line which best fits the data for the conditions under which the samples were collected. Projection of the line beyond

$$* f = \frac{k_2}{k_1} = \frac{\text{reaeration rate}}{\text{deoxygenation rate}}$$

the range of conditions under which the data was collected is not recommended. However, the data may be extrapolated to conditions within the range of data with a reasonable degree of certainty. The stream equation for Cayadutta Creek, developed by extensive analysis can be used to compute B.O.D. reductions necessary to maintain a certain minimum dissolved oxygen at a given temperature. These calculations are shown on the following pages and in Figures 2 and 3.

Figures 2 and 3 indicate that for maintaining 2 ppm of dissolved (a preselected safe value for this class stream) oxygen at 23,750 #BOD/day loading at the bottom of the sag at a temperature of 12.4° C., B.O.D. reductions of from 65 to 94 percent and 77 to 97 at 35, 019 #/day would be required for critical stream flows of from 12 to 25 cfs.

#### D. Composite Wastes Analyses

Waste samples were collected hourly from the three sources, Johnstown 30" sewer (main), Johnstown 8" sewer (Tynville), and the Gloversville Sewage Treatment Plant on Nov. 17 and Dec. 3, 1964 for a 24 hour period. Similar samples were collected for a 24 hour period on the 21st of January 1965 except that the 8 inch Johnstown sewer was eliminated as being relatively insignificant. Weirs were installed

in the Johnstown lines to record the total flows from Johnstown as well as Gloversville. Samples were collected and composited according to the rate of flow occurring at the hour of sampling. A summary of the proportionate pollutional loads and volumes for these three days is shown in Table 8. Additional 24 hour composites from each line were collected according to flow and analyzed on February 18, 1965; March 30, 1965; April 21, 1965; and May 6, 1965. The analyses of these samples are reported in Tables 9, 10, and 11.

## 11. LABORATORY PILOT PLANT STUDIES

In order to form more definite conclusions on the proper units to be included in the waste treatment plant, certain small scale laboratory studies were deemed necessary. These included sludge digestion and activated sludge treatment.

### A. Sludge Digestion

A mixture of primary and secondary settled sludge was collected from the settling basins at the Gloversville Treatment Plant. A pilot digester consisting of a glass container and a gas collecting system was set up at 37°C. in the Akerbauer Laboratory in Johnstown. The raw sludge sample selected was analyzed for organic matter at the start of the "batch" digestion period and again after 50 days of digestion. The gas volume was measured almost daily during this period. The results are shown in Table 12.

Although this was a "batch" type experiment 9.07 cubic feet of gas were produced over the 50 day period per pound of volatile matter destroyed. It may be expected that greater amounts of gas will arise from a continuous digestion operation maintained at optimum environmental conditions. More gas would have evolved in this experiment after an increased digestion period. It has slowed down considerably, however, after 50 days. Normal gas production for sewage sludge is about 15 ft<sup>3</sup> /# organic matter destroyed. It will be necessary to carry out digestion experiments under continuous basis and over a longer period in order to ascertain whether an accumulated toxic effect exists.

However, Vrooman and Ehle <sup>(14)</sup> also reported successful digestion of this waste sludge.

#### B. Activated Sludge Treatment

Tannery waste was shipped from the G. Levor tannery in Gloversville to Syracuse and the pilot lab experiments were carried out at the Sanitary Engineering Laboratories at Syracuse University by Mr. Stephen Gaie of the Civil Engineering Department. This particular tannery was chosen since it consisted of both beamhouse and tanyard facilities and tanned various types of hides using predominantly chrome tans.

Since settling was expected to be an integral part of a biological treatment plant of this type, the apparatus used in the study consisted of an aeration tank with two mixers and three air diffuser stones. The air flow ( $\text{ft}^3$  air/hour) was measured by a previously calibrated rotameter. The tank was 23.5 inches long, 8.5 inches wide, and was filled to a depth that gave an aeration volume of six gallons.

Various mixtures of settled tannery waste (1:1 mixture of beamhouse and tanyard wastes) and settled domestic sewage were added to the aeration tank in a semi-batch procedure to simulate, as closely as possible in the laboratory, continuous operation. The standard aeration period of six hours was used with the waste mixture added in three increments of two gallons each at intervals of two hours. The tank contents were settled for a period of about one hour prior to the addition of the first increment of waste mixture. Next, two gallons of the supernatant were siphoned off and two gallons of the waste mixture added. This procedure resulted in the addition of six gallons of waste mixture in a period of four hours for a total aeration time of eight hours and an average aeration period of six hours as shown below.

<sup>14</sup>Vrooman, M. and Ehle, Virgil, Sewage and Industrial Wastes 22, 1, 94, January 1950

Time (hrs.)	Vol. added (gals.)	Aeration time (hrs.)
0	2	8
2	2	6
4	2	<u>4</u>
Average -		6 hours

The results obtained are summarized in Table 13 and shown graphically in Fig. 4. Each loading represents about one week's aeration data with samples being taken for analyses several times during this week of adaptation and acclimation.

Laboratory experiments verified that this waste would degrade biologically to the extent of 65-75 percent even when loaded at the high rate of 95-115 pounds B.O.D. per 1000 cubic feet of aerator. (See Fig. 4). Higher B.O.D. reductions (75-85) were obtained with lower B.O.D. loadings (60-82#BOD/1000 ft<sup>3</sup>) and increased dilution of the tannery waste with domestic sewage.

These studies show that activated sludge or a modification of the process could be utilized successfully in the overall treatment of the combined tannery and sewage wastes. Larger prototype field experiments should disclose whether these results can be projected directly to full scale operation.

The present Gloversville treatment plant has experienced much difficulty due to its overloaded condition. However, from the best records available, and when all the flow units of the plant were operating about, 58-60 percent B.O.D. was removed. This also shows that biological degradation by trickling filtration is possible with this waste under full-scale field conditions. The exact degree of this oxidation could be determined more easily in a properly designed and operated field pilot plant.

#### CONCLUSIONS FROM STUDY

This study led the writer to the following specific conclusions:

- 1 - The stream survey was instrumental in providing evidence that secondary treatment of the



of the combined industrial and sanitary wastes of the area is required and that 65 to 94 percent B.O.D. reduction will be needed depending upon the dilution available in the stream. Use of the curves plotted in Figs. 2 and 3 will allow for a more precise selection of B.O.D. reduction required for the specific critical stream flows.

- 2 - The present dry weather flow to be treated averages 6.724 million gallons per day, with peaks of 2 to 3 times this rate. About 50 percent of this flow originates from the industries of the area.
- 3 - The combined area waste contains an average of 23,442 pounds of 5 day, 20°C B.O.D. and 20,650 pounds of suspended solids per day. These loadings can be affected quite considerably by the type of skin tanned - deerskin being an especially significant contributor of high B.O.D. and solids loads.
- 4 - Laboratory pilot studies demonstrated that the conventional activated sludge treatment process is capable of reducing the B.O.D. of the combined waste by 65 to 85 percent (depending primarily upon the organic loading) at loadings ranging from 60 to 115 pounds of B.O.D. per 1000 cubic feet of aerator capacity.
- 5 - A digestion batch experiment yielded about 9 cubic feet of gas per pound of volatile matter destroyed and affected a 71 percent reduction in organic matter.
- 6 - A literature study confirmed the findings of the laboratory results in that the combined wastes of this type are amenable to biological oxidation.
- 7 - Because of the unique nature of the volume and characteristics of the tannery sewage waste mixture as well as the size and cost of the project, field prototype studies should precede full-scale treatment construction.

- 8 - Additional laboratory research should be instigated on development of improved methods of aerobic biological treatment of tannery wastes to allow for greater B.O.D. reduction at higher B.O.D. loadings.

#### 111. DECISION ON PROTOTYPE (PILOT PLANT)

The cost is too high, the risk too great, and the previous experience too little to recommend full-scale biological treatment at this time. A prototype in the field - preferably at the site of the Gloversville treatment plant - should be built and operated for about 4 to 6 months to obtain detailed data for the final design and to obtain greater certainty that our findings to date are valid. This prototype should contain both trickling filtration and activated sludge (as well as provision for its modifications) units. It should also allow for experimentation with series and parallel operation of the units and both diffused and mechanical aeration. Some sludge digestion studies should be carried out over the entire period.

#### Prototype Operating Data

A schematic drawing of the field prototype is shown in Figure 5. It consists of two sets of screens in series (1/2" openings followed by 1/4" openings), pump, primary settling, trickling filter, aeration, and final settling. The plant began operation in early August 1965 and sampling was begun on August 16th. Analyses to date are shown in Table 14.

#### 1V. FINAL TREATMENT PLANT - PROCESSES (Recommendations)

We specifically recommend and are including in our preliminary planning the following treatment units and processes:

- a. Three mechanically cleaned bar rack screens to remove large debris from the flow.
- b. Two circular grit removal units designed on surface overflow rate to remove grit and sand prior to primary settling.



(Separation and washing of settled grit and organic matter by two hydro-cyclone classifying devices.) Prior to final design, consideration is to be given to utilization of aerated grit removal unit.

- c. Disposal of screenings and grit in sanitary landfill.
- d. Grease removal by skimming in the primary settling tanks. Grease flotation facilitated by aeration following or incorporated with grit removal unit and immediately preceding the primary settling tanks.
- e. Possible future chemical application in the aeration structure for pH control and introduction of chemicals to aid precipitation of wastes, for short periods, at times of exceptionally low flows in Cayadutta Creek.
- f. Possible future addition of coagulating chemicals in the flow to the secondary clarifiers for "polishing" of effluent and/or in the discharge from the secondary clarifiers for control of algal nutrients, if found necessary. (Structure provided for addition of coagulating chemicals in inflow.)
- g. Six rectangular primary settling tanks with mechanical sludge collectors and scum skimmers.
- h. Biological secondary treatment in two stages by the following:
  - (1) Two high-rate (roughing) filters with stone or plastic media and rotating arm distributors, followed by:
  - (2) Activated sludge treatment (in multiple units) in two sections, with mechanical aeration units directly powered by electric motors.

- i. Two circular secondary settling tanks with sludge and scum collection mechanisms, sludge collectors to be of the "vacuum cleaner" type.
- j. High-rate digestion provided through a primary digester followed by a secondary digester. Floating covers on both digesters with gas collection and holder facilities. Gas utilization for heating of sludge and buildings. Gas recirculation mixing in both digesters would be provided with possible operation of either digester as primary.
- k. Dewatering of digested sludge and disposal of sludge cake by approved landfill methods.

Sludge dewatering and disposal could be provided by three possible means:

Method A - Dewatering by lagoons  
Disposal by approved  
landfill methods

Method B - Dewatering by vacuum  
filters  
Disposal by approved  
landfill methods

Method C - Dewatering by vacuum  
filters  
Incineration (multiple-  
hearth)  
Disposal of ash by  
landfill

Final recommendations and determinations must consider:

- (1) Net annual costs reflecting capital costs and operation.
- (2) Physical problems involved in the handling of the sludge as increasing amounts are disposed of over the years.
- (3) Future utilization of the land considered for landfill.

## V. SOLIDS HANDLING

The quantity of raw solids estimated to be handled at the plant is 170,000 pounds per week of which approximately 70 percent are of industrial origin, primarily tannery.

A review of existing secondary wastewater treatment plants in the United States and Canada handling a large percentage of solids disclosed four plants that were treating tannery effluents in combination with municipal wastewaters. All four plants utilize digestion. Two of the plants dispose of digested solids in liquid form on wastelands using tank trucks, one lagoons the digested solids and one vacuum filters, dries, and landfills the dried sludge. All of the plants are able to effectively digest the solids.

The problems with the digestion of the tannery-municipal solids have not been primarily chemical or biological but physical. Hair and scum have caused serious problems in the digesters themselves and in digestion tank appurtenances. Extensive pretreatment, including fine screens, have been necessary at some plants to reduce operational problems. The screens have in some cases introduced another problem, that of blinding.

The Cities of Gloversville and Johnstown are surrounded by a rural area providing land for landfill of the final residue from the sludge handling system. Both cities operate refuse landfill operations and both presently own large areas of land designated for future landfill use. Landfill of the dewatered solids from the wastewater treatment plant could be accomplished.

A review of construction and operational costs indicated that digestion of solids and dewatering in lagoons would provide the most economical solution to conditioning and dewatering of the solids. This solution was discussed extensively with the regulatory agencies and with the Gloversville-Johnstown Joint Sewer Board who have responsibility for administering the project. This solution was eventually eliminated.

There was considerable interest in the wet air oxidation system being used to condition and to destroy organic solids. This system was viewed as being capable of treating industrial solids without possible upset by the changing chemistry of the leather industry. The Zimpro Division of Sterling Drug had considerable experience in handling similar solids at South Milwaukee and in Kempen, Germany. The wet air process also offered the added advantage of producing a solid that was readily filterable. The filterability of either raw or digested solids have been considered a potentially troublesome and expensive operation.

The final selection of sludge handling process was low pressure (300 psi) wet air oxidation plant, with vacuum filters for dewatering and ultimate disposal of solids in landfill. The wet air plant as designed will reduce the non-soluble organic solids by 40 to 50 percent. The High BOD filtrate will be pumped to a holding tank and discharged to the head of the plant during low BOD load periods.

The wet air plant will have capacity to handle the weekly solids loading in 5 days on a 16-hour per day schedule or in 3 1/2 days on a 24-hour schedule. The plant is basically one unit with duplication of several key items of equipment.

The two vacuum filters will dewater cake from the oxidized sludge holding tank. The oxidized sludge holding tank will be equipped with overflow weirs and a sludge collector. The dense sludge pulled from the tank will be filtered during the 8-hour day shift, 5 days per week.

The final solution to the sludge handling problem is not conventional but the unusual solution does fit the unique problem for these communities in their location and with their industries.

#### VI. ESTIMATED COSTS AND FINANCING:

The project costs and the Federal and State grants are estimated as follows:

Interceptor Sewers	\$1,227,000
Wastewater Treatment Plant	<u>4,600,000</u>
	\$5,827,000
All Other Costs and Contingencies	<u>1,212,000</u>
Total	\$7,039,000
Less Federal and State Grants	<u>3,981,000</u>
Net to Community	\$3,058,000

It is estimated that the plant will have twenty full-time employees. Annual operational and maintenance costs are estimated at \$262,000. The local communities will receive a reimbursement from the State of New York in the amount of one-third of this cost leaving a local net cost of \$175,000.

The estimated total annual costs for the project and their distribution between the cities is as follows:

Annual Debt Service (30 years at 4 1/2%)	\$220,000
Annual Net Operation and Maintenance Costs	<u>175,000</u>
	\$395,000

#### Distribution

City of Gloversville (55%)	=	\$217,250 per year
City of Johnstown (45%)	=	<u>177,750</u> per year
Total		\$395,000

The agreement between the Cities of Gloversville and Johnstown calls for a 55 - 45 percent split of capital costs and of operation and maintenance every 3 years. The division of operation and maintenance charges will change every three years reflecting the results of samples collected and analyzed.

The final method of allocating costs to the users has not been fully established at this time, although certain principles have been established. The two cities are desirous of keeping the rates in the cities the same. The rates will be based upon the volume of water used and there will very likely be surcharges to industrial users. It is the aim

of the Sewer Board and the cities to avoid a rate structure that is dependent upon repeated and critical sampling of industrial users. The average homeowner in the cities will pay for the service based upon his water usage and present estimates put the average annual cost of less than \$20 per year per home.

TABLE 1

## CAYADUTTA CREEK ANALYSES DURING OCTOBER 1964

Station	Date Oct. 1964	DO (ppm)	Flow *cfs 10-31 34	BOD 1st day (ppm)	BOD 2nd day (ppm)	BOD 3rd day (ppm)	BOD 4th day (ppm)	BOD 5th day (ppm)	Temp. C
			11-1 42						
1	10-8	10.12						8.0	8
Bleeker St.	10-12	9						8.5	13
Bridge	13	10						9.5	12
Gloversville	14	10.5						10.0	10
(clean H <sub>2</sub> O site)	15	9						8.5	11
240-89 (14.25)	17	9.5						9.3	12
just above	18	10.0						8.9	11
4	10-8	1.0						310	12.5
Main St.	12 1:30	1.9						240	15
Johnstown	13 10:15	0.5						290	13
240-89 (8.25)	14 9:00	5.1						340	10
	15 4:00	2.7						280	12
	17 11:05	6.2						240	12
	18 1:30	6.0						30	12
5	8	2.75		140	230	260	290	340	11.5
Harding Property	12 2:00	2.8		110	180	220	260	290	15
below Johnstown	13 10:25	5.0		100	130	130	140	150	14
240-89 (6.75)	14 9:30	3.1		120	190	170	180	200	14
	15 4:30	3.0		100	140	160	210	220	13
	17 11:25	5.4		100	70	130	150	160	14
	18 2:05	5.5		70	70	100	140	140	15

(continued)

TABLE 1 (continued)

Station	Date Oct. 1964	DO (ppm)	Flow *cfs 10-31 34	BOD 1st day (ppm)	BOD 2nd day (ppm)	BOD 3rd day (ppm)	BOD 4th day (ppm)	BOD 5th day (ppm)	Temp.
6	8	2.2	59.4	130	200	270	300	330	13
Sammons ville Br.	12 2:25	1.8	51	140	170	250	230	240	14
240-89 (4.75)	13 10:45	1.1	44	40	70	60	80	140	12
	14 9:45	4.6	39	110	150	140	150	180	11
	15 4:50		39	40	110	150	160	160	12
	17 11:55	4.8	12.2	40	30	100	100	70	12
	18 2:40	4.8	12.2	40	30	50	50	40	13
7	8	1.25						190	11
Rt. 334 Adjacent	12 2:45	0						200	14
Peresse Rd.	13 11:10	4.1						140	12
Berryville Cross	14 10:05	5.0						170	11
240-89 (3.0)	15 5:15	3.9						80	10
	17 12:15	1.8						70	11
	18 3:10	4.0						50	11
8									
Rt.334 1 mile	8	5.1						180	10.5
north of Fonda	12 3:05	3.5						90	13
next to	13 11:30	5.1						140	11
Cannarella House	14 10:20	5.1						160	11
240-89 (1.4)	15 4:30	5.0						80	12
	17 12:45	3.6						100	11
	18 3:30	4.5						40	



TABLE 2

TIME OF FLOWS FROM SITE 5 DOWNSTREAM TAKEN BY  
 VROOMAN ABOUT 1 WEEK BEFORE STREAM SAMPLING  
 PROGRAM IN OCTOBER 1964

Start at Harding Farm (Station 5)	Distance between points (miles)	Time (hrs. & min.)	Fall (feet)
to old Power dam	1	45 min.	70
to Bridge at Sammons ville (Station 6)	1	2 hrs.	20
to Bridge at Fonda Ave.	1-3/4	2 hrs.	80
to Bridge No. Railroad	1-1/2	2 hrs. 40 min.	55
Begin slack water Mohawk	1	2 hrs. 30 min.	50
	<hr/>	<hr/>	<hr/>
Totals	6-1/4	9 hrs. 55 min.	275

TABLE 3

SUMMARY OF 7 DAY SAMPLING OF CAYADUTTA CREEK  
DURING DRY PERIOD FROM 10-8-64 TO 10-18-64

					RANGE
Sta. 1.	D. O. (ppm)	9.73	Avg.	7 samples	9-10.5
	Temp. (°C)	11	Avg.	7 samples	8-13
	BOD (5 day, 20°C, ppm)	8.96	Avg.	7 samples	8-10
Sta. 5	D. O. (ppm)	3.93	Avg.	7 samples	2.75-5.5
	Temp. (°C)	13.8	Avg.	7 samples	11.5-15
	BOD (5 day 20°C, ppm)	214	Avg.	7 samples	140-340
	BOD (L)	270	Avg.	7 samples projected	
				Factor	1.26
	BOD (1 day)	106	Avg.	7 samples	70-140
	BOD (2 day)	144	Avg.	7 samples	70-230
	BOD (3 day)	167	Avg.	7 samples	100-260
	BOD (4 day)	196	Avg.	7 samples	140-290
	Time of Travel Between Sta. 5 and 6 - 2 hr.45 min. - 0.115 days				
Sta. 6	D. O. (ppm)	3.17	Avg.	7 samples	1.1-4.8
	Temp. (°C)	12.4	Avg.	7 samples	11-14
	BOD (5 day, 20°C, ppm)	116	Avg.	7 samples	40-330
	BOD (L)	230	Avg.	7 samples projected	
				Factor	1.39
	BOD (1 day)	77	Avg.	7 samples	40-140
	BOD (2 day)	109	Avg.	7 samples	30-200
	BOD (3 day)	146	Avg.	7 samples	50-270
	BOD (4 day)	153	Avg.	7 samples	50-300
	*Flow (CFS)	36.7	Avg.	7 samples	12.2-59.4

\*Flow for 10-12-64 computed as arithmetic average of flow  
on 10-8-64 and 10-13-64.

TABLE 4

## FLOW DATA FROM \*KAYADERASSEROS CREEK

YEAR	MINIMUM FLOW (cfs) 90 mi <sup>2</sup> Daily	MINIMUM DIALY EQUIVALENT FLOW OF CAYADUTTA CREEK AT STA. 6 cfs
1927	13	$\frac{62 \times 13}{90}$ 8.9
1928	18	12.4
1929	24	16.5
1930	19	13.1
1931	19	13.1
1932	20	13.8
1933	19	13.1
1934	20	13.8
1935	34	23.4
1936	20	13.8
1937	21	14.5
1938	20	13.8
1939	20	13.8
1940	23	15.9
1941	15	10.3
1942	23	15.9
1943	29	19.3
1944	21	14.5
1945	26	17.9
1946	20	13.8
1947	22	15.2
1948	18	12.4
1949	14	9.6
1950	23	15.9
1951	32	22.
1952	31	21.4
1953	20	13.8
1954	23	15.9
1955	20	13.8
1956	32	22.
1957	19	13.1
1958	20	13.8
1959	18	12.4
1960	25	17.2

\*Hydrologically similar to Cayadutta Creek

TABLE 5

A NORMAL PROBABILITY DISTRIBUTION  
ANALYSIS OF DATA (1927-1960) FROM TABLE 5

FLOW	MAGNITUDE (M)	M/N - 1 (Plotting position)
8.9	1	1/35 - .0286
9.6	2	2/35 - .0572
10.3	3	.0858
12.4	4	.1143
12.4	5	.1430
12.4	6	.1715
13.1	7	.2000
13.1	8	.2290
13.1	9	.2570
13.1	10	.2860
13.8	11	.3140
13.8	12	.333
13.8	13	.371
13.8	14	.400
13.8	15	.428
13.8	16	.458
13.8	17	.486
13.8	18	.515
13.8	19	.544
14.5	20	.571
14.5	21	.600
15.2	22	.629
15.9	23	.658
15.9	24	.685
15.9	25	.715
15.9	26	.744
16.5	27	.770
17.2	28	.800
17.9	29	.829
19.3	30	.858
21.4	31	.887
22.0	32	.916
22.0	33	.945
23.4	34	.974

TABLE 6

CHURCHILL METHOD OF ANALYSIS OF CAYADUTTA CREEK  
Cayadutta Creek Analyses During October 1964

Date	D. O. at Sta. 1 (ppm)	D. O. at Sta. 6 (ppm)	Drop in D. O. (ppm) Y	B.O.D. at Sag (ppm)	Temp. at Sag (°C)	Flow at Sag (cfs)
10-8	10.1	2.2	7.9	330	13	59.4
10-12	9.0	1.8	7.2	240	14	51
10-13	10.0	1.1	8.9	140	12	44
10-14	10.5	4.6	5.9	180	11	39
10-15	9.0	2.9	6.1	160	12	39
10-17	9.5	4.8	4.7	70	12	12.2
10-18	10.0	4.8	5.2	40	13	12.2

Waste Treatment Requirements Under Conditions of \*(12 cfs)  
Minimum Flows, Average Oct. 1964 Stream Temperature, and  
Minimum D. O. Sag allowable.

Using Stream Equation developed during low flow, critical period for Cayadutta Creek (October 1964)

$$Y = 4.9330 + .0769 X_1 + .2574 X_2 - .5826 X_3$$

When  $X_1 = 1000/\text{ppm BOD}$

$$X_2 = \text{Temp. } (^{\circ}\text{C}) = 12.4 \text{ (See Table 24)}$$

$$X_3 = 100/\text{cfs} = \frac{100}{12} \text{ (See Fig.16)} = 8.33$$

$$Y = \text{D. O. sag from Sta. 1 to Sta.6} \\ 9.73 - 2.00 = 7.73$$

$$7.73 = 4.9330 + .0769 X_1 + .2574 (12.4) - .5826 8.33$$

$$7.73 + 4.85 - 4.9330 - 3.200 = .0769X$$

$$12.58 = 8.133 = \frac{4.447}{.0769} = X_1 = 57.75$$

$$\text{ppm} = \frac{1000}{57.75} = 17.3 \text{ ppm at sag}$$

\*This flow represents the approximate value of the 7 day consecutive low flow likely to occur in Cayadutta Creek below Johnstown once in ten years.

$$\frac{62}{90} \times 120 = 13.8 \text{ cfs for entire Cayadutta Creek (Slightly less for below Johnstown)}$$

<sup>1</sup> Minimum 7 day flow for Kayaderosseras Creek according to N.Y.S. Upper Hudson River Drainage Basin Survey Series Report No. 2, pg. 244.

TABLE 7

Date 1964	Sta. 1 (ppm)	D. O. at Sta. 6 (ppm)	Drop in D. O. (ppm)	B. O. D. at Sag 1000/ppm	Temp. at Sag °C	Flow in cfs at Sag 100/cfs										
			Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Y <sup>2</sup>	YX <sub>1</sub>	YX <sub>2</sub>	YX <sub>3</sub>	X <sub>1</sub> <sup>2</sup>	X <sub>1</sub> X <sub>2</sub>	X <sub>1</sub> X <sub>3</sub>	X <sub>2</sub> <sup>2</sup>	X <sub>2</sub> X <sub>3</sub>	X <sub>3</sub> <sup>2</sup>
10-8	10.1	2.2	7.9	3.03	13	1.68	62.41	23.94	102.7	13.27	9.18	39.39	5.09	169	21.84	2.82
10-12	9.0	1.8	7.2	4.17	14	1.96	51.84	30.02	100.8	14.12	17.39	58.38	8.17	196	27.44	3.84
10-13	10.0	1.1	8.9	7.14	12	2.27	79.21	63.55	106.8	20.20	50.98	85.68	16.21	144	27.24	5.15
10-14	10.5	4.6	5.9	5.56	11	2.56	34.81	32.80	64.9	15.10	30.91	61.16	14.23	121	28.16	6.55
10-15	9.0	2.9	6.1	6.25	12	2.56	37.21	38.13	73.2	15.62	39.06	75.00	16.00	144	30.72	6.55
10-17	9.5	4.8	4.7	14.29	12	8.20	22.09	67.16	56.4	38.54	204.20	171.48	117.48	144	98.40	67.24
10-18	10.0	4.8	5.2	25.00	13	8.20	27.04	130.00	67.6	42.64	625.00	325.00	205.00	169	106.60	67.24
SUMS			45.9	65.44	87	27.43	314.61	385.60	572.4	159.49	976.72	816.00	381.88	1087	340.40	159.39
MEANS			Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>										
			6.56	9.35	12.4	3.92										
							-2	NYX <sub>1</sub>	NYX <sub>2</sub>	NYX <sub>3</sub>	NX <sub>1</sub> <sup>2</sup>	NX <sub>1</sub> X <sub>2</sub>	NX <sub>1</sub> X <sub>3</sub>	NX <sub>2</sub> <sup>2</sup>	NX <sub>2</sub> X <sub>3</sub>	NX <sub>3</sub> <sup>2</sup>
Corrected items n = no. of samples = 7							NY	429.38	569.38	180.04	611.94	811.51	256.56	1076.32	340.26	107.56
Correct sums								-43.78	3.02	-20.55	364.78	4.58	125.32	10.68	0.14	51.83
								13.40								

TABLE 8

## SUMMARY OF 24 HOUR SAMPLING RESULTS

		#/day	B. O. D. Load		Flow mgd	Flow		#/day	Suspended Solids	
			% in 6-12 Noon load	% of Total		Ratio of 6-12 Rate to avg. daily	% of Total		% in 6-12 load	% of Total
Gloversville	11-17-64	13,350	45.2	67.5	3.80	1.38	66	27,550	80.8	87.5
	12-3-64	13,350	50.2	56.3	3.67	1.34	50	11,100	61.6	53
	1-21-65	23,400	41.1	63.1	3.96	1.35	60.5	21,600	25.8	63
Johnstown #1	11-17-64	6,400	44.8	32.2	1.92	1.55	33.4	4,100	57.7	12.5
	12-3-64	15,000	27.5	42	3.60	1.46	49	18,400	42.0	45
	1-21-65	13,600	43.2	36.9	2.58	1.33	39.5	12,800	37.0	37
*Johnstown #2	11-17-64	102.4	25.4	0.53	.0449	1.24	0.6	32.9	56	
	12-3-64	223	25.2	1.4	.0809	.925	1	213	17.9	2.0
Total	11-17-64	19,852			Total	5.7649		Total	31,683	
	12-3-64	28,573				7.3509			29,713	
	1-21-65	37,000				6.54			34,400	

\* 8" sewer



TABLE 9

## ADDITIONAL 24 HOUR COMPOSITE WASTEWATER ANALYSES

	Feb.18-19, 1965	
	Gloversville	Johnstown
Flow (mgd)	3.41	3.05
B.O.D. (ppm)	405	385
(#/day)	11,500	9,800
pH	9.4	8.3
Total Solids (ppm)	3130	2450
Total Ash (ppm)	2250	1570
Total Vol. (ppm)	880	880
Susp. Sol. (ppm)	258	81
Susp. Ash (ppm)	140	48
Susp. Vol. (ppm)	118	33
(%)	46	41

Solids Analyses of Settled (2 hr.) Sludge

Total Solids (%)	1.54	0.88
Total Ash (%)	34.4	37.5
Total Org. (%)	63.6	62.5

TABLE 10

24 HOUR COMPOSITE ANALYSES OF JOHNSTOWN  
AND GLOVERSVILLE WASTEWATER  
on March 30, 1965 and April 21, 1965

		<u>Johnstown Outfall No. 1</u>	
		<u>March 30, 1965</u>	<u>April 21, 1965</u>
Total Solids (ppm)		1,970	1,840
Suspended Solids (ppm)		145	213
Volatile (SS) (ppm)		96	135
BOD (5 day, 20 C., ppm)	285-330 (307 Avg.)	386-371 (378 Avg.)	
Settleable Solids	5.5	4.5	
SS on Supernatant	70	86	
VS " "	52	60	
BOD " "	225-355	386-326	
Average 24-hour Flow	4.88	2.84	
Average 6 a.m.-12 noon	6.33	3.00	

		<u>Gloversville Outfall</u>	
		<u>March 30, 1965</u>	<u>April 21, 1965</u>
Total Solids	2,430	2,542	
Suspended Solids	265	418	
Volatile (SS)	196	265	
BOD	300-435 (367 Avg.)	435-371 (403 Avg.)	
Settleable Solids	20.0	13.0	
SS on Supernatant	97	128	
VS on " "	78	92	
BOD " "	95-180 (330-285)	281-266	
Average 24 hr. Flow	3.05	3.63	
Average 6 a.m.-12 noon	4.73	4.29	

SAMPLE MARCH 30, 1965 - BASIC DATA

<u>Gloversville</u>		<u>D. O.</u>
24-hr. Composite (2 cc/300 mi.)		2.9, 3.8
2-hr. settled effluent (2cc/300mi.)		4.6, 4.9
Blank		5.8
2-hr. Settleable Solids - 20.0		
<u>Johnstown</u>		
24-hr. Composite		3.9, 3.6
2-hr. settled supernatant		3.7, 4.3
Blank		5.8
2-hr. settleable solids - 5.1		

24 HOUR COMPOSITE ANALYSES OF JOHNSTOWN  
AND GLOVERSVILLE WASTEWATER  
ON MAY 6, 1965

Average 6 a.m. - 2 p.m. - 5.9 mgd.

TABLE 11 (Continued)

Sample Location - Johnstown Outfall No. 1

Sample Date - May 6, 1965

**Total Solids - 2962**

**Suspended Solids - 322 ppm**

Volatile - 250 ppm

BOD - 585 ppm)  
) (Average 562)  
BOD - 540 ppm)

Settleable Solids (24-hr.) - 16.0

**Suspended Solids (Supernatant) - 135 ppm**

Volatile " - 110 ppm

BOD (Supernatant) - 405 ppm

BOD " - 375 ppm

**Suspended Solids (8-hr.) - 423 ppm**

Volatile " - 310 ppm

BOD 8-hr. - 435 ppm)  
BOD 8-hr. - 405 ppm) (Average 420)

Average 24-hr. Flow - 2.07 mgd.

**Average 6 a.m. - 2 p.m. - 2.92 mgd.**

TABLE 12

## SLUDGE DIGESTION (Laboratory Study)

Accumulated gas produced (ml)	Digestion at 37 C. (Days)		
250	1	grams organic (raw)	5.4533
290	2		
460	3	grams organic (after 50 days)	1.5542
640	4		
730	5	loss of organic matter (grams)	3.8991
850	6		
940*	7	loss of organic matter (%)	71.2
990	8		
1040	9	gas produced (cc)	2200
1140	10		
1140	11	gas produced (cc/gram org.)	567
1150	12	destroyed	
1190	13	gas produced (cc/gram V.M. added	403
1240	14		
1290	15	$2200 \times .000353 = .0777 \text{ ft.}^3$	gas produced
1340	16		
1380	17	$\frac{3.8991}{454}$	= .00858# V.M. destroyed
1420	18		
1480	19		
1540	20	$\frac{.0777}{.00858}$	= 9.07 ft. <sup>3</sup> gas/# org. matter destroyed
1600	21		
1650	22		
1700	23		
1820*	24		
1900	25		
1940	26		
1980	27		
1980	28		
2010	29		
2020	30		
2030	33		
2040	36		
2050	40		
2060	41		
2080	42		
2090	43		
2110	44		
2150	47	*Gas collected changed	
2170	49		
2200	50		

TABLE 13  
ACTIVATED SLUDGE PILOT LABORATORY STUDIES

	B. O. D. Loading (#/1000 Ft <sup>3</sup> )	Susp. Solids Under Aeration (ppm)	Air Rate (ft <sup>3</sup> /#BOD removed)	Influent B. O. D. (ppm)	Effluent B. O. D. (ppm)	Reduction in B. O. D. (%)
5 gallons Sewage + 1 gallon tannery waste mixture	60	2330	2450	239	44	8.16
4 gallons Sewage + 2 gallons tannery waste mixture	82.8	2221	1900	331	78	76.5
3 gallons Sewage + 3 gallons tannery waste mixture	114.7	2768	1735	459	165	64.1
5 gallons Sewage # wastes (Gloversville) + 1 gallon Sewage wastes from Johnstown	70	3386	2000	280	39	86
4.015 gals. Gloversville 2.112 gals. Johnstown #1 0.044 gals. Johnstown #2	73.8	2508	2116	295	68	76.9
3 gallons tannery waste mixture + 3 gallons tap H <sub>2</sub> O	93.0	2646	1070	374	91	75.6

DATE	RAW WASTE			PRIM. EFF.			T.F. EFF.			FINAL EFF.			SUSP. SOLIDS	pH
	BOD	pH	S.S.	BOD	pH	S.S.	BOD	pH	S.S.	BOD	pH	S.S.	Under aeration	
*8-16-65	655	7.6	603	448	7.3	248	353	7.3	251	93	7.2	139	1430	7.2
*8-17-65	468	8.4	528	373	8.3	256	241	7.6	202	81	7.2	44	1603	7.3
*8-18-65	468	9.1	578	380	9.0	170	230	8.5	262	73	7.4	75	-	-
8-19-65	563	8.0	369	390	8.0	211	268	7.6	187	85	7.2	78	1850	7.3
8-20-65	493	8.5	-	408	8.7	281	256	8.3	166	73	7.4	84	2631	7.6
**8-23-65	443	7.0	382	433	7.4	145	316	7.5	243	72	7.5	43	2313	7.4
**8-24-65	555	8.1	393	425	8.1	134	330	7.8	250	90	7.4	89	2066	7.5
**8-25-65	370	7.9	392	313	7.8	169	398	7.8	394	79	7.4	197	2487	7.5
**8-26-65	408	8.3	454	360	7.8	243	231	7.5	168	102	7.3	127	2788	7.2
**8-27-65	273	8.8	337	308	8.5	135	215	8.1	155	19	7.6	53	-	-
**8-30-65	298	7.9	347	210	8.1	111	124	7.5	116	25	7.4	47	1848	7.6
**8-31-65	250	7.9	379	230	7.9	230	163	7.8	214	24	7.5	67	1934	7.4
**9-1-65	423	7.8	460	260	7.9	292	256	7.8	260	54	7.5	160	854	7.6
**9-2-65	483	8.6	550	408	8.4	350	435	8.4	360	96	7.5	166	2243	7.8
**9-3-65	455	7.9	431	315	7.9	311	238	8.0	205	141	7.3	216	2775	7.6
**9-9-65	563	8.1	486	418	8.2	82	275	7.9	87	76	7.4	264	2430	7.9
**9-10-65	563	7.9	262	413	7.4	110	290	7.4	137	51	7.1	218	2500	7.4
**9-13-65	563	8.4	329	453	8.1	154	290	8.2	142	112	7.4	180	2219	7.6
**9-14-65	628	8.7	392	538	8.6	240	351	7.6	210	162	7.4	366	1899	7.4
**9-15-65	658	7.6	356	568	7.6	257	349	7.5	178	69	7.0	22	2653	7.2
**9-16-65	623	9.0	235	593	8.5	108	368	8.5	105	62	7.5	19	3025	7.6
**9-17-65	635	7.6	284	460	7.6	60	348	7.5	96	75	7.1	44	3226	7.5
**9-21-65	720	7.9	425	425	7.8	199	215	7.6	178	135	7.4	130	2300	7.5
**9-22-65	530	7.2	435	450	7.0	167	204	7.0	166	55	7.0	338	2892	6.9
**9-23-65	490	8.0	349	393	8.0	173	183	7.6	224	33	7.3	51	2790	7.5
**9-24-65	730	8.7	288	523	8.5	192	170	8.3	115	111	7.5	140	2490	7.8
**9-27-65	543	8.5	306	383	8.4	247	233	7.8	240	117	7.4	93	2326	7.6
**9-28-65	480	8.1	403	420	8.0	197	289	7.8	193	127	7.6	124	2361	7.8
**9-29-65	516	-	315	463	-	177	258	-	180	126	-	141	2664	-
**9-30-65	650	8.1	307	490	7.6	145	344	7.5	195	192	7.4	157	2096	7.4
**10-1-65	435	7.8	312	363	7.6	162	280	7.6	229	158	7.2	241	1495	7.4

TABLE 14  
PROTOTYPE OPERATING DATA

The writers are sincerely indebted to the following persons whose assistance made this study possible.

Morrell Vrooman, Jr.	for making the resources of his firm available to the writers
Stephen Gale	for carrying out the laboratory studies on activated sludge treatment
Carl Acherbauer	for carrying out laboratory digestion study and for making all the laboratory analysis of the field samples
Edwin L. Barnhart	for providing valuable evaluation of the results as the study proceeded
Robert Wendell	for his assistance in obtaining tannery samples data and cooperation.





REGISTRATION





"TECHNIQUES OF DEEP WELL DISPOSAL -  
A SAFE AND EFFICIENT METHOD OF POLLUTION CONTROL"

BY

ROBERT S. STEWART  
PRESIDENT

AMERICAN INDUSTRIAL DISPOSAL SYSTEMS INC.

PITTSBURGH, PENNSYLVANIA.

My invitation to address this conference came through a meeting in the Toronto offices of the Ontario Water Resources Commission. Subsequently, I was specifically requested through the good offices of Mr. Voegel, Program Chairman, and Mr. Clark, to point out the advantages and disadvantages or, if you will, dangers that may exist in this method of pollution control. In addition to this, I was requested to discuss, in some detail, probable costs of installation and operation of such systems.

Our Company has now been in this field for a good many years (approximately 18 years to be exact) and having been so far in the forefront of recommending this method of disposal, we have found that in almost every case we are presenting a proposal to local, state or federal commissions or regulatory bodies for the first time and as a brand new subject. We have received, and only naturally so, a rather startled reaction in many cases. It is somewhat similar to an engineer proposing to put a manually operated capsule into orbit in 1950 and asking somebody's permission to do so. This has created a very real dilemma for many of the regulatory bodies that are responsible to the public for guarding their welfare where natural resources are concerned.

It is a tough decision to make and the situation can only be improved by supplying the concerned commissions and regulatory bodies with authentic, good and detailed information on which they may rely and upon which they can formulate opinions and ask additional questions which can assist them in arriving at the appropriate decision.

I happened to be reading the May, 1968 issue of Reader's Digest and found the following small article which I quote verbatim: "In a discussion of the water pollution problem threatening a California beach, a County Flood Control District spokesman asked for a delay for further study saying 'we don't want to be in favor of something we might be opposed to if we knew what it was' ". It is very obvious that any responsible body lacking sufficient information on a method submitted to them must find, somewhere, the basic data that would allow them in good conscience to approve or disprove the method. Therefore, I will attempt to outline, in very simple form, the primary information necessary in an evaluation of the deep well disposal method of pollution control. First, I will cover the very basic principles of how it works.

1) It is first necessary to have a subsurface horizon, preferably a uniform sandstone, but under certain circumstances a limestone, or dolomite, or even a shale might be satisfactory.

2) Ideally, this horizon should be filled with salt water which is normally the case in the subsurface. This formation of salt water should be unquestionably unuseable as a potable water source and, I suppose, specifically unuseable in the knowledge of the current time as a material source for the chemical industry.

3) This horizon should be located at a sufficient depth and in a suitable geologic sequence so there might be no contamination of any water source that may be of use now or in the future for the local communities. The intent of this requirement would be the establishment of the fact that there is a good and sufficient cap rock above the disposal horizon which would prevent vertical migration of any deleterious waste into a useable potable water source.

In the majority of cases, these requirements can be satisfied but not in every locality. There are areas in the United States and there is a vast area in the eastern part of the Dominion of Canada where these requirements cannot be met. However, competent geology can indicate such a situation in advance of any consideration of using this method of pollution control.

I have just described the theoretical requirements of deep well disposal and now, as I said before, I will give you a run-down of disadvantages or dangers involved.

The primary danger, and I underline the word, and the question of most concern to the governmental agencies, is the pollution of ground water. This danger can be eliminated through original proper consideration and proper design. A correctly engineered and equipped disposal well will prevent mechanical failures that might permit vertical migration of the waste. The nature of the subsurface where it has been adequately considered and adequately inspected will prevent any vertical migration due to other causes than mechanical failures.

I am going to bring up the subject of earthquakes caused by the injection of fluid wastes in the subsurface. I think this is necessary only because one such well - the Rocky Mountain Arsenal Waste Disposal Well No. 1 in Colorado - did cause minor earthquakes. This subject well, of great interest obviously to our profession, has been exaggerated beyond belief and is still getting considerable publicity. I will say to you now that the disposal fluid in that well did cause the tremors, but it was a known fact at that time that the well was being drilled into a severely faulted section, and I would guess that the thought might have been that the actual presence of the faulting would enhance the ability of the formation to take fluid; and I am sure that it did. In case there is anyone in my audience who is not familiar with a fault, consider two planks of wood resting against each other where some force is required to slide one plank on the other one. The retarding force, of course, is friction but if you lubricate the surface between the two planks with any fluid, including water, the friction force will be reduced and the movement will be easier. This is exactly what happens when you lubricate a fault in the subsurface. But remember this: it is not cause for panic. In most areas, faults are either known to exist or not to exist and any prudent operator would avoid such areas. This is not a criticism of the Colorado well, as this matter would probably not have occurred to anyone had it not been for this experience. Now many members of the geological profession think this might be a good way to control earthquakes using the obvious method of letting the faults adjust themselves gradually instead of building up a major catastrophe.

Next, I would like to go into the question of primary design for the disposal well itself.

All the techniques of drilling a deep well disposal and equipping it in satisfactory manner are derived from the

oil and gas industry. However, here the similarity ends. A well drilled for deep well disposal in the accustomed manner of drilling and equipping an exploratory well for oil and gas would be entirely inadequate. The primary concern in drilling and equipping a waste disposal well is to provide a permanent installation free of any possible defects that could allow contamination of the potable water sources or potential mineral sources that might lie in the same subsurface.

In order to do this, it is an absolute necessity to exercise elaborate control over the drilling program, the casing program, and the cementing program. I have here a diagram on which I would like to point out these various safety precautions that must be used not only to combat any contamination problems, but also to assure the owner of a long term trouble-free installation.

As you look at this diagram, you will see a proposed equipment plan that calls for three strings of steel casing in addition to the injection tubing. We consider the injection tubing to be in a separate category, since the type of tubing used will depend on the corrosive or non-corrosive nature of liquid waste.

The steel casings are designed to prevent any contamination of the subsurface by the fluid waste.

It is our contention and also our normal design recommendation to drill over-sized holes and use elaborate cementing equipment and methods on each string of casing so that the thickness of cement and quality of the cement job will negate any possibility of vertical migration through mechanical failure.

This Figure #1 which you see displayed is a more or less average installation showing the proper method of equipping a waste disposal well.

There is more than one method of equipping these wells which involved the treatment of the annular space around the injection tubing, but I will leave this matter for the discussion period since it can become rather involved.

Last, but not least, I would like to discuss in general terms cost of such an installation and operation. The cost is not an easy subject to handle for the simple reason that all disposal wells are different. First they differ in depth - second, they differ in purpose - and third, they differ in the type of waste that must be handled. It is obvious that a deeper well costs more than a shallower one. It is also obvious that a big disposal problem measured in gallons per minute costs more than a smaller

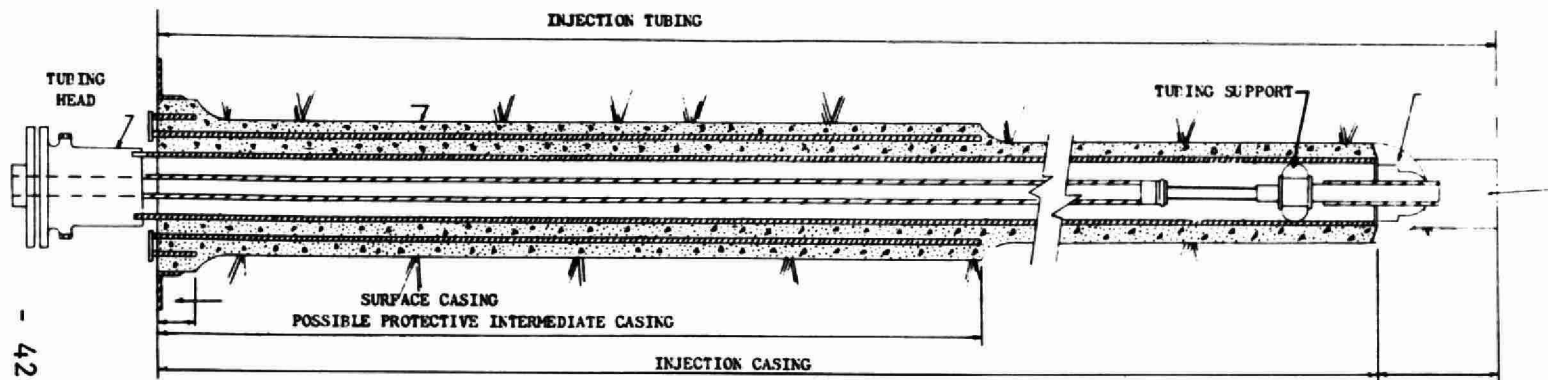
disposal problem and it is certainly obvious that the cost of handling a corrosive waste is more expensive than handling a non-corrosive waste.

Essentially, we are dealing with a method here that is most satisfactory in handling a good sized problem of liquid waste and I will arbitrarily choose a number somewhere between 50 and 75 gallons per minute on a 365 day basis. It costs no more basically to handle twice that amount but as your waste problem goes down, your operating cost, which we must relate to a unit cost or gallon cost, must go up.

From our experience, which ranges from extremely expensive and extremely high pressure disposal wells to modestly priced and low pressure disposal wells, the cost, considering everything, is about one-third of any other method of neutralization.

I am sure you will have many questions, most of which I hope I can answer, but I believe I have already gone over the time limit allocated to me or, should I say, suggested to me by the Program Chairman.

Thank you very much for your kind invitation to speak before your conference.



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# PROPOSED SUBSURFACE DISPOSAL WELL

BY  
AMERICAN INDUSTRIAL DISPOSAL SYSTEM, INC.

No Scale  
Preliminary Fig. 1

Schematic  
No Date



SESSION CHAIRMAN  
DR. W. R. HORN  
RESEARCH CO-ORDINATOR  
THE MINING INSTITUTE OF CANADA



"INCINERATION OF PROCESS INDUSTRY WASTES"

BY

W. K. LOMBARD, P.ENG.  
VICE-PRESIDENT AND GENERAL MANAGER  
TRECAN, LTD., COOKSVILLE, ONTARIO.

Every industrial plant has something left over as a waste. This waste may be a liquid, a solid or bulk material, a gaseous waste or fume, or it may be a combination of any of these.

The plant that can discharge all its waste liquids into the municipal sewer system, properly remove all its bulk materials and allow all of its gaseous wastes to exhaust into the air is indeed fortunate. In all probability such a plant does not need to send representatives to this conference.

That such a plant exists within the process industry is unlikely. It is thus to these industries that we direct our comments. We would like to describe several specific types of incineration equipment applicable to this industry, and we would like to recap the history preceding the construction of a facility to handle the wastes from several such industrial plants.



By "process industries" we refer generally to -

- chemical plants
- refineries
- food processing plants
- petro-chemical plants
- paint and varnish plants
- chemical processes within metallurgical  
and other manufacturing operations

These industries need to keep a continual review of their waste disposal procedures because the government agencies with jurisdiction in these matters are getting teeth to their jurisdiction. They are also getting funds and personnel to enforce their regulations. This is particularly true here in Ontario with agencies such as the OWRC and the Ontario Department of Health. It has been mostly talk occurring at the Federal level both in the United States and Canada but this also is gradually changing with continual funding and stepped up sampling and monitoring facilities.

It may not be much longer before plants producing liquid wastes that cannot be put into the sewer system will be allowed to place them into lagoons or have them hauled away in the dark of night. Open dumping of bulk wastes will require proper land-fill procedures. Gaseous wastes or fumes containing pollutants will not be freely allowed to go to the atmosphere.

One of the methods which should be examined as a means of destroying such wastes is combustion, or as it is referred to when dealing with wastes, incineration.

Combustion can change an organic liquid or vapour, or a mixture of an organic and water, into carbon dioxide and water vapour. These are not pollutants. Combustion can change sulphur compounds or sulphonated hydrocarbons into carbon dioxide, water vapour and sulphur dioxide. Granted, sulphur dioxide is no bargain but it is better than hydrogen sulphide or a mercaptan and is generally capable of dilution so that ground level concentrations are acceptable.

Chlorine or fluorine bearing organic materials can be changed by a combustion process, with subsequent scrubbing, to a weak hydrochloric or hydrofluoric acid which in turn can be neutralized.

Combustion or incineration of wastes is, of course, not the answer for all materials and there are many which cannot be destroyed by incineration. These include sodium or potassium caustic materials, aluminum chloride and other metallic salts, iron oxide, and leaded compounds.

When considering incineration, it is, of course, most important as a starting point that the makeup of the waste material be known as accurately as possible. If this cannot be obtained by the knowledge of the process that the waste comes from, it is worth having a laboratory analysis made of a sample.

### The Combustion Process

Before examining some specific types of incineration equipment for specific types of waste, we feel that the fundamentals of a good combustion process and thus a good incineration process should be reviewed.

All incinerator equipment must have air, as a source of oxygen, and the 3 T's of good combustion:

Temperature  
Turbulence  
Time

The amount of air in the incinerator must be the right amount; not too much since this can chill the combustion process. Too little will, of course, not allow completion of the burning. Incineration temperatures are generally in the range of 1400F to 2600F. They are rarely under 1000F except with the aid of catalysts.

Turbulence is required to obtain intimate mixing between the waste material and the oxygen in the combustion air system. This intimate mixing requires pressure drop which in turn requires energy somewhere in the system, usually in the form of electrical horsepower.

The time for incineration is usually between 0.3 seconds and 1 second provided the right temperature and turbulence conditions exist. Bulk materials, particularly those of some physical size of consequence will require longer times because the material can only expose its outer surface to the temperature and turbulence and burn from the outside in.

### Types of Wastes

We would now like to review some examples of types of incinerators for specific types of waste. These wastes can be categorized as follows:

- A. Rich liquids
- B. Weak liquids
- C. Halogenated liquids
- D. Fumes
- E. High heating value bulk materials

A rich liquid is referred to as an organic with a heating value high enough to sustain combustion as though it were a liquid fuel. This usually means 8000 Btu/lb or higher. This can still be a material having a fairly high water content, as much as 50%. Auxiliary gas is usually required for ignition of such a liquid waste and possibly for preheating the system in some cases. However, it can usually be turned off after a few minutes.

The first slide (Fig. 1) shows a simplified diagram of such an incinerating burner. It is shown discharging into the base of a stack. This is usually done so that the hot combustion gases can be dispersed above ground level and also for personnel protection. The stack is not required for proper incineration. Since the burner uses a forced air system, the stack draft effect is not needed. The flame temperature is around 2400 to 2800F. Fig. 2 shows such a rich liquid - paint lacquer waste - being burned at about 50 GPH.

Other examples of the types of materials that can be destroyed in this type of incinerating burner would include solvents such as toluene, acetone and benzene. Some other liquids are styrene, glycols, waste oils and amines. Fig. 3 shows the burning of 50 GPH of solvent. Fig. 4 shows the burning of 200 GPH of a heavy separator oil waste.

The unit can also fire straight up, with an extension forming a stack for dispersion, as shown in Fig. 5. These units will cost in the range of \$10-\$15,000. for burning capacities of around 500 lbs/hr of liquid. For a 2000 lb/hr unit, the cost would be in the range of \$20-\$25,000. The stack cost is not included.

Weak liquids are those having small percentages of organics but which are mostly water. The organic percentages are usually below 5% but in some cases can go up as high as 50% and still be categorized as a weak liquid. They are not capable of sustaining combustion without help from an auxiliary fuel. The auxiliary fuel can, of course, be conventional oil or gas, but it could be another waste material which would be considered a rich waste as discussed above.

The next slide (Fig. 6) diagrams this type of incineration chamber which we normally refer to as a two-stage system. The primary combustion zone is considered the first stage, which is where the auxiliary fuel or rich waste is being burned. The temperature here is around 2600F or higher. The second stage is the chamber into which the weak liquid is sprayed and the combination of flows usually results in a temperature level in this second chamber of between 1400 and 1800F.

It is important to ensure in this type of two stage unit that complete combustion in the first stage occurs before

the weak liquid is sprayed into the system. If this is not done, a chilling of that first stage combustion can occur and the resulting temperature level is too low. This is particularly important if a waste is being burned in the first stage. Mixing and the right amount of oxygen in the second stage is equally important.

Examples of materials which we would classify as weak liquids and would be incinerated in this type of unit include phenol water, various washing and flushing fluids and separator sludges which are usually weak mixtures of oil and water. Incidentally, with the washing fluids, it is important to watch for small amounts of caustic. These can be tolerated, provided the quantity is small enough.

The next slide (Fig. 7), shows a photograph of this type of incinerator in a vertical arrangement. The cost of a 500 lb/hr unit of this type is in the range of \$15-\$20,000. and the auxiliary fuel requirement is around 2 million Btu/hr. A 2000 lb/hr weak liquid incinerator would cost around \$35-\$40,000. and would take about 8 million Btu/hr worth of auxiliary fuel. Again, depending on the location, a stack may be added to these units. These units can usually be shop fabricated as shown in Fig. 8, which is a 1500 lb/hr incinerator.

Another approach to the incineration of aqueous wastes, is to add a rich waste or a conventional fuel to them to make the mixture rich enough to burn as though it were a rich liquid. This arrangement usually requires a somewhat higher incineration chamber temperature, and thus a higher fuel cost, than the two stage incinerator, since the burner must be at equilibrium and this is at least 1800F. The lower initial cost, however, justifies this as long as the waste flow, and thus the auxiliary fuel flow, is not too high. We usually recommend the two stage approach if the higher initial cost can be paid for in less than one year by the lower auxiliary fuel cost.

It is possible with either rich or weak liquids for there to be particulate matter, either in the original liquid or formed in the incinerating process. If any appreciable quantity is involved, it may be necessary to incorporate a means of collecting these particles. This can either be a mechanical collector, a low energy wet scrubber or a high energy venturi type scrubber. The choice will depend on the specific particle size and the quantity involved. Most liquid chemical wastes do not involve particulates to the extent that they cannot be filtered out prior to the burning process and thus such scrubbing equipment is not usually needed.

Most halogenated liquid wastes are chlorinated hydrocarbons. These are usually burnable as in the classification of a rich liquid because they are primarily a hydrocarbon and only have one or two chlorine or sometimes fluorine atoms attached. Nevertheless, special equipment is required because the chlorine will pass through the reaction. This is shown here for a typical chlorinated hydrocarbon such as ethylene dichloride:



If plenty of caustic solution is available for scrubbing, this can be used to take out the chlorine. But such quantities of caustic are not always readily available. A better solution is to use some auxiliary gas such as natural gas or propane as an auxiliary fuel; not for helping combustion, but as a means of obtaining some extra hydrogen in the process so that HCl will be produced rather than free Cl. The reaction with natural gas thus becomes:



In practice, some extra  $\text{CH}_4$  is added to make sure that all of the Cl goes to HCl. This will produce a small amount of carbon monoxide (generally less than 1%) but this is, of course, much better than producing Chlorine.

Scrubbing of the effluent is now possible with water, and the HCl will go into solution as a very weak hydrochloric acid. It is generally less than 1% depending on how much water is available for the scrubbing. This weak acid can thus be easily neutralized if necessary with, for example, lime.

The incinerating chamber portion of such a unit for a chlorinated material is essentially the same as for any rich liquid, but a scrubber is needed on the downstream end. The next slide (Fig. 9) shows a photo of this type of equipment with a tower type of scrubber.

The next slide (Fig. 10) shows a burner unit arranged to fire so that there is a submerged exhaust to the combustion gases. Consequently, they must bubble through water and the scrubbing occurs by direct contact. This arrangement is most economical in smaller sized systems, up to about 1000 lbs/hr.

Some of the typical materials we encounter for this type of equipment includes trichlorethylene, ethylene dichloride and propylene dichloride. Typical costs would be about \$25,000.-\$30,000. for a 500 lb/hr system with about



2 million Btu/hr worth of auxiliary gas required and about 200 gals/min of water needed for scrubbing. A 1500 lb/hr system would cost between \$40-\$45,000. and would require 6 million Btu/hr worth of gas and around 400 GPM of scrubbing water.

Gaseous wastes or fumes are primarily streams of air with small quantities of organics which may cause a visible plume and often an odour. The percentage of organics in these streams is generally a matter of a few percent and often times can be fractions of 1%.

The term "afterburner" is often applied to this type of incinerator.

The next slide (Fig. 11) diagrams a typical fume incinerator unit which is essentially an auxiliary burner system firing into a chamber in which the fume is directed to ensure the right combination of temperature, turbulence and time. Sometimes the fume is so nearly all air, that it can be used as combustion air for the burner, as shown in Fig. 12.

Examples of the type of fume encountered for this application, which is generally from a process exhaust system, include fumes from painting baking and drying ovens, food processing and cooking exhausts, sulphur recovery tail gas and solvent application systems. These solvent systems can occasionally have a relatively rich concentration of solvents, and we have even seen cases where the fume is near the combustible point. A fume incinerator will, of course, work fine for such a situation, but solvent recovery equipment is more than likely justified rather than incineration because of the high solvent value.

The next slide (Fig. 13) shows a photograph of such an incinerator which is used to burn the tail gas from a sulphur recovery process. These units cost around \$10-\$15,000. for a fume flow of 4,000 SCFM and around \$20-\$25,000. for a fume flow of 10,000 SCFM.

Bulk Wastes having a heating value appreciably higher than such things as paper, cardboard and scrap lumber require special consideration for incineration. Such materials would include scrap pieces or sheets of plastic materials such as polyethylene, polypropylene or nylon as well as materials such as rubber and oil soaked rags and paper. These materials can have heating values ranging from 10,000 Btu/lb to as high as 19,000 Btu/lb and because of this do not usually burn properly in conventional modular incinerators.

The type of incinerator we utilize for such materials is shown in the photograph in the next slide (Fig. 14). This bulk waste incinerator design was originally developed by the E.I. du Pont de Nemours & Co., in the United States, and they have built several for their own use. It consists of a refractory lined rectangular chamber which is open at the top and into which a carefully directed stream of combustion air is forced. This provides the right combination of turbulence and oxygen to achieve the desired temperature levels for clean and efficient combustion. These units can either be built as a chamber located above grade or as a pit in the ground. The overhead screening is used to catch any floating lightweight material such as paper.

For an incinerator of this type having a capacity in the range of 2 to 3 tons per hour of bulk wastes, the cost is in the range of \$35-\$40,000.

### Heat Recovery

We would like to insert a comment at this point on the matter of heat recovery since this is frequently brought up for consideration with respect to incinerating systems, since it is easy to see that a great many Btu's are going out to the atmosphere. Generally, the types of heat recovery systems which can be practical are those to heat water, generate steam or to preheat the feed to the incinerator in cases where auxiliary fuel is required so that the amount of that auxiliary fuel is reduced.

It is our recommendation that such recovery equipment be considered only if the savings or by-product created will pay for the additional initial cost in no more than one year. Also, it is important when considering heat recovery equipment that the makeup and flow of the waste material is accurately known since variations can cause changes in temperature and combustion patterns which, in turn, can affect the value and life of the heat recovery sections of the system. Of course, fouling and corrosion need to be examined as well.

The next slide (Fig. 15) shows a diagram of a combination of incinerator and recuperator section, wherein the incoming waste gas stream is being preheated from the incinerating chamber section. Such a modification will usually add at least 50% to the initial cost of the system and even more if another fluid is being heated such as a hot water or steam generating section.

Another means of reducing the auxiliary fuel required in a fume incinerator is the use of a catalyst bed to allow combustion to occur at a lower temperature. Here again, the

chemical analysis of the waste is important to know, to insure reasonable catalyst life.

With a high water content liquid waste, pre-concentration using the submerged combustion technique can lower the amount of auxiliary fuel required. These methods are most likely to be worth considering in the larger sized systems.

### Central Disposal Facility

Incineration equipment such as we have been describing is sophisticated and expensive machinery. It needs to be in order to be able to do the proper job. However, there is seldom a return to the investment made and a Plant Manager must, therefore, look long and carefully at making such an investment. On the other hand, he must also be confident that some dependable means of taking care of his waste materials is always available to him.

For gaseous wastes, incineration or whatever treatment is used will undoubtedly need to be done locally at the plant due to the difficulty in transporting such fumes any distance.

For liquids and bulk materials, however, the cost for the equipment and its operation is bound to be lower per unit of input, the higher the input flow which can be achieved. A centrally located disposal facility serving a number of sources of such waste materials would seem to be a logical answer to such a situation. This is practical, of course, only in an area where several industrial plants have the kinds of materials needed to properly add to the input flow, and provided someone is available to properly construct and run such a facility.

We would, therefore, like to present a preliminary review of such a waste disposal facility which is now under construction. This facility is owned and will be operated by Goodfellow Enterprises (Sarnia) Ltd. of Corunna, Ontario and has been designed by Trecan Limited. It is located about 10 miles southeast of Sarnia and will serve the chemical and refinery complex located along the St. Clair River known commonly as Canada's "Chemical Valley".

This facility will have 2 incinerating burners for rich liquids, a bulk waste incinerator for high Btu materials, a conventional travelling grate incinerator for low Btu bulk materials, a burial area for inert wastes and a deep well for clean aqueous liquids. A lagoon area is also included which will be used for settling purposes and as a temporary storage area. A scrubbing system for use with



chlorinated materials could not be included due to the lack of a good water supply. Heated storage tanks for 60,000 gals. are included as part of the facility.

This facility is currently under construction and will be in operation later this summer. We are, therefore, not describing the operating features of this installation at this time. We certainly hope to be able to do so in the future.

### A Case History

Our purpose in bringing it to your attention is that we feel it may be of interest to briefly review the history leading up to the present construction phase since a similar history could easily be involved in an undertaking in some other industrial area.

Ideal circumstances existed with respect to this undertaking, in that the area involved has a very high industrial plant concentration. Good co-operation among these plants has been evidenced in the past, particularly with respect to problems connected with pollution. An enterprising contractor was already involved in physically removing liquid and bulk wastes from these industries.

The initial step leading up to the present status was that of the Ontario Department of Health deciding that the open dumping of all of these waste materials by the contractor, Stanley Goodfellow, needed to be stopped and they so advised him as well as the companies he was serving. The Department of Health did not put a specific time limit on the matter of changing to a better way of handling these wastes, but they did insist that some positive steps be undertaken promptly.

At this point, Goodfellow decided that he was willing to pursue the matter further and try to come up with a proper solution. This step was very significant in this whole matter since he could have decided to go fishing.

Goodfellow financed a technical survey to examine all of the wastes being generated by these plants to not only establish the nature of the materials being collected but what would represent a practical facility design to dispose of them.

This survey report, which was prepared by Trecan Limited, was reviewed with all of the companies involved as well as the Department of Health, the OWRC and the Department of Energy and Resources Management before it was finalized.

A careful estimate was then made to determine what would be the new costs for disposing of the wastes, based on the projected new facility and what it would cost to operate. A revised schedule of charges was drafted which would need to be made by Goodfellow to the industrial plants he served.

Each company was then asked whether it would be willing to pay for its waste disposal on the basis of these new charges which ranged from 25% to 200% higher than what it was then paying.

Every company responded affirmatively.

Trecan, on behalf of Goodfellow, then proceeded to request specific approval to proceed with the new facility from the following organizations:

The Ontario Department of Health  
The Ontario Water Resources Commission  
The Lambton County Medical Office  
The Ontario Department of Energy and  
Resources Management  
The Township of Moore (where the plant  
would be located)

There were no significant problems in obtaining approvals from the first four organizations noted. We were dealing with technical people who understood the system design and all of its ramifications. The last one was very difficult. A zoning by-law was needed to allow the property involved, which was about 100 acres, to be used as a waste disposal facility. Objections from local rate payers were loud and enduring but they were finally overcome with the considerable help of personnel from the Department of Health as well as the Town Council itself who properly realized the need for the facility.

Once all of these approvals were obtained, engineering and design work for the actual construction immediately got underway and we hope that the entire facility will be finished and in operation within a couple of months from now.

Assuming that the plant is in operation in August of 1968, it will have been 23 months from the time of the first notification by the Department of Health.

In addition to being responsible for the design and construction of this facility, Trecan Limited is also going to provide continuing technical surveillance of the operation and to be available for examination of any new or changing materials which are certain to show up as time goes on. It is, of course, important for any operator of such a waste disposal plant to have his staff available either permanently or on call.

It can be readily seen that for an undertaking of this type to be successful, close co-operation among all the parties involved is vital. Just as vital is the proper tolerance by the Government regulatory agencies.

This Sarnia facility has been designed to be dependable, flexible and capable of expansion and to be in keeping with the regulations. It is also designed to operate at a profit. If it does all of these, and we firmly believe that it will, it represents a practical answer to a most pressing problem.

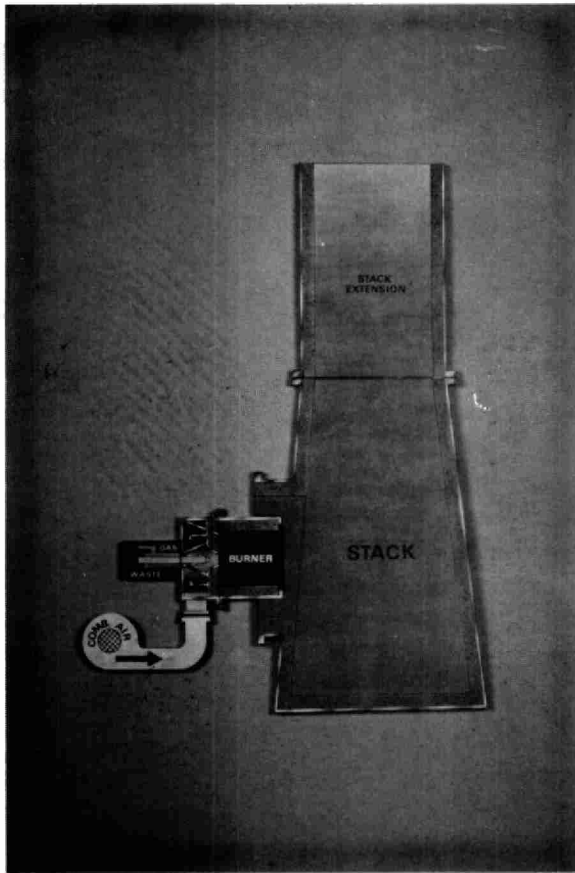


Fig.1 - Burner Firing into  
Base of Stack

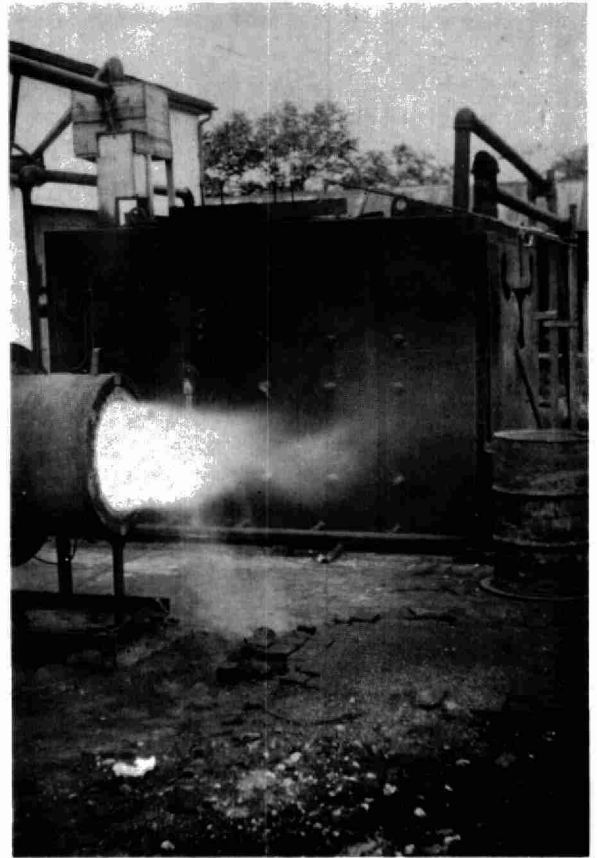


Fig.2 - Direct Burning of Medium  
Weight Liquid Waste -- 50 GPH



Fig.3 -- Direct Burning of Light Solvent  
Waste -- 50 GPH

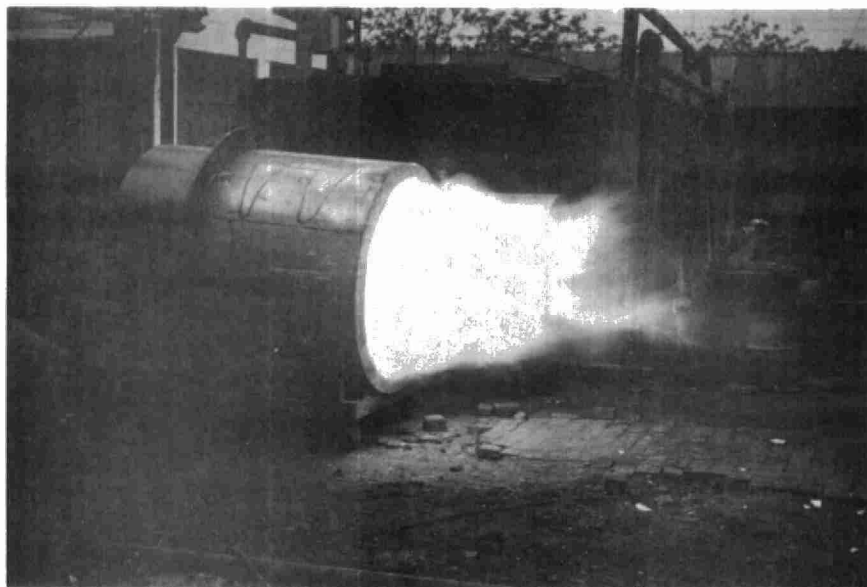


Fig.4 - Direct Burning of Heavy Liquid  
Waste -- 200 GPH

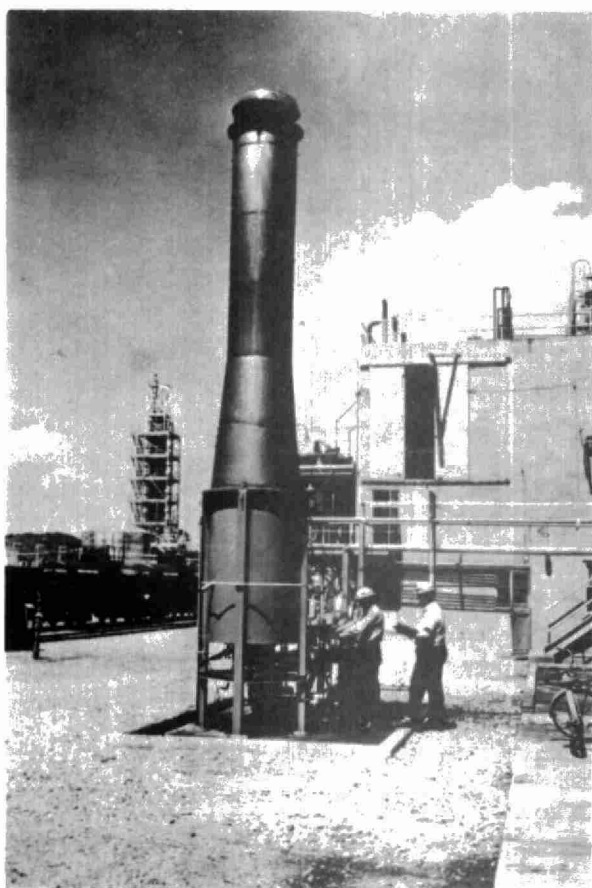


Fig.5 - Vertically Fired Incineration  
Burner with Stack

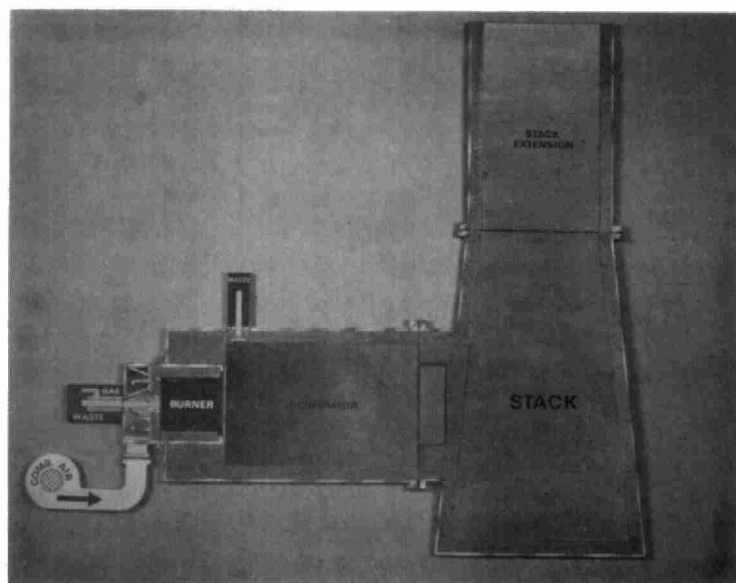


Fig.6 - Two Stage Liquid Incinerator



Fig.7 - Two Stage Liquid Incinerator  
Vertically Fired

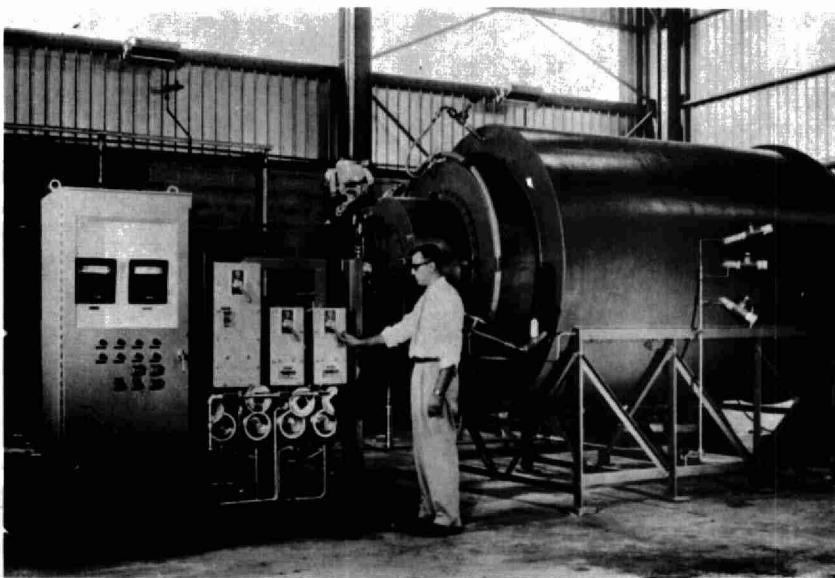


Fig.8 - Shop Fabricated Two Stage  
Liquid Incinerator

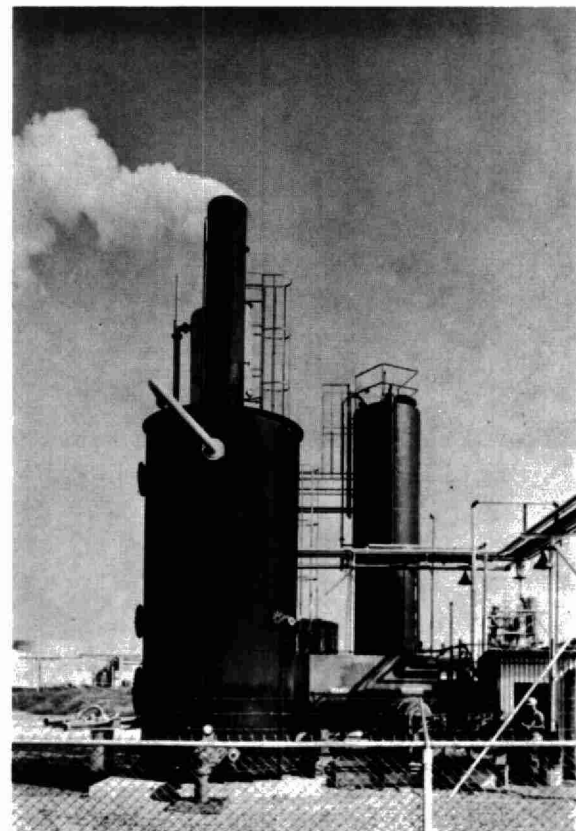


Fig.9 - Liquid Incinerator with  
Tower Scrubber

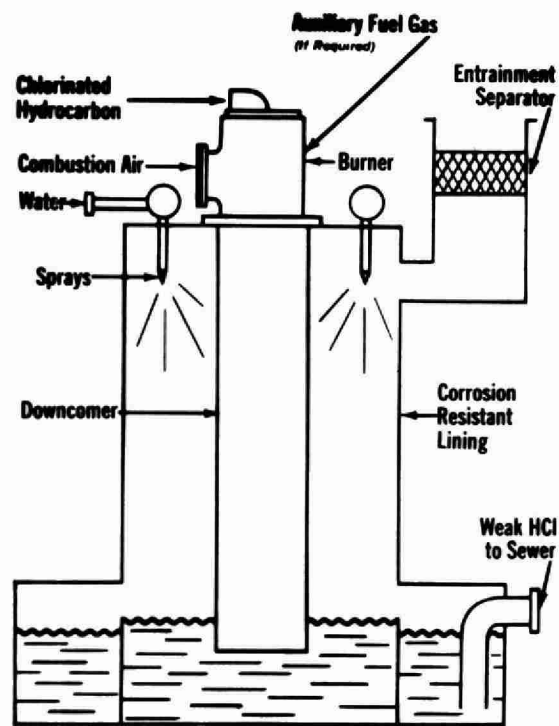


Fig.10 - Diagram of Sub-X Type Direct Contact Scrubber

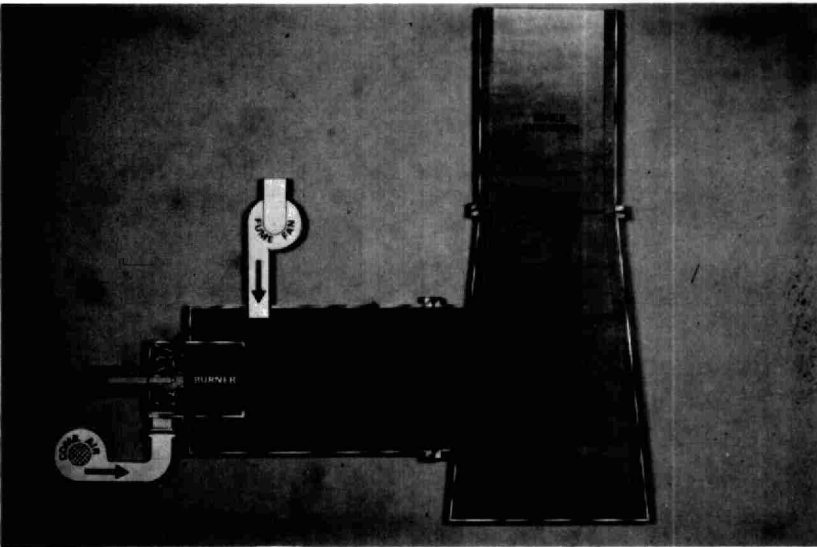


Fig.11 - Fume Incinerator with Stack

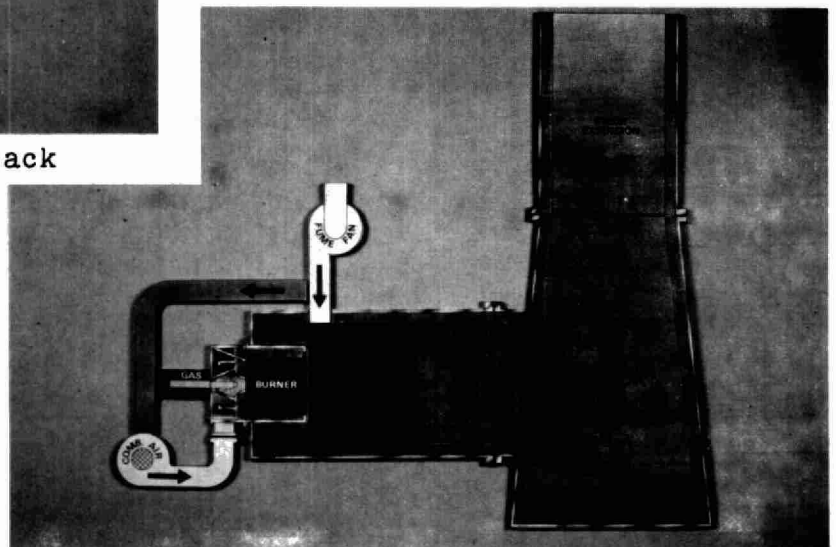


Fig.12 - Fume Incinerator with Fumes Passing Through Burner



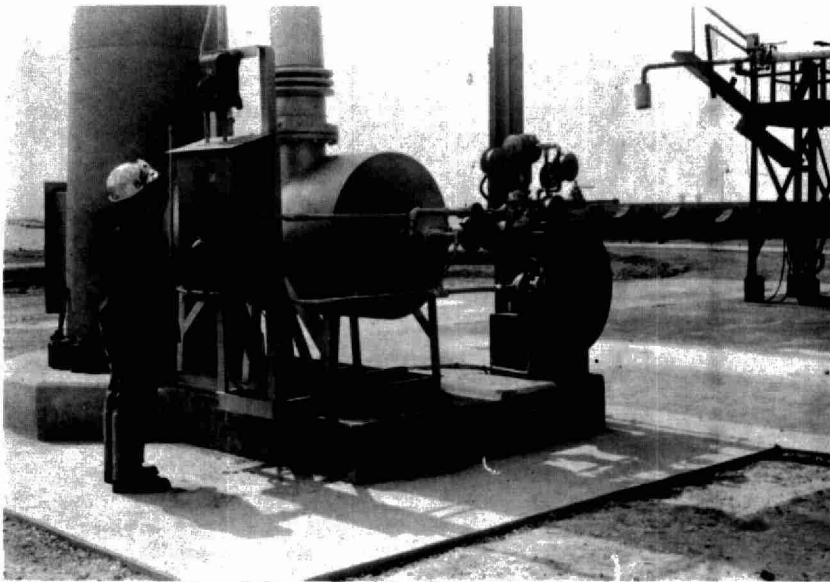


Fig.13 - Tail Gas Incinerator

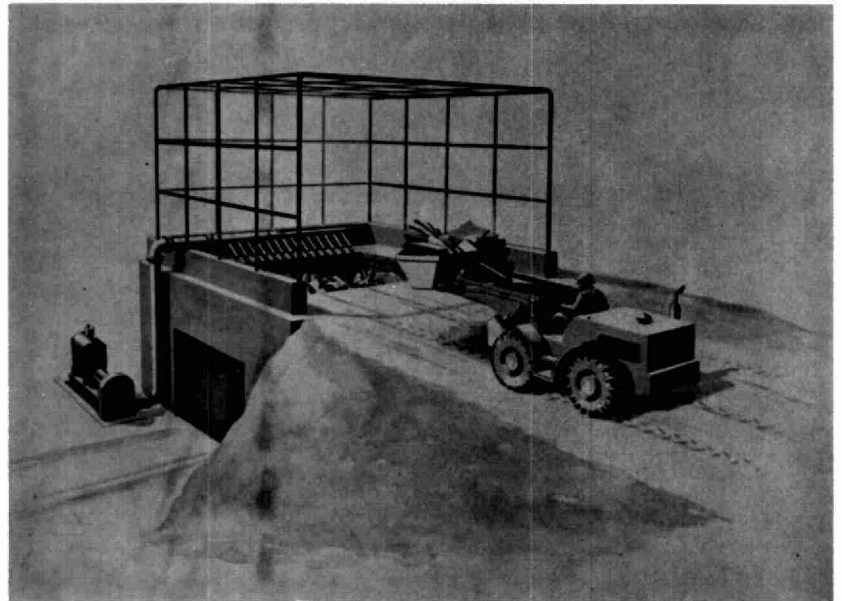


Fig.14 - Bulk Waste Incinerator

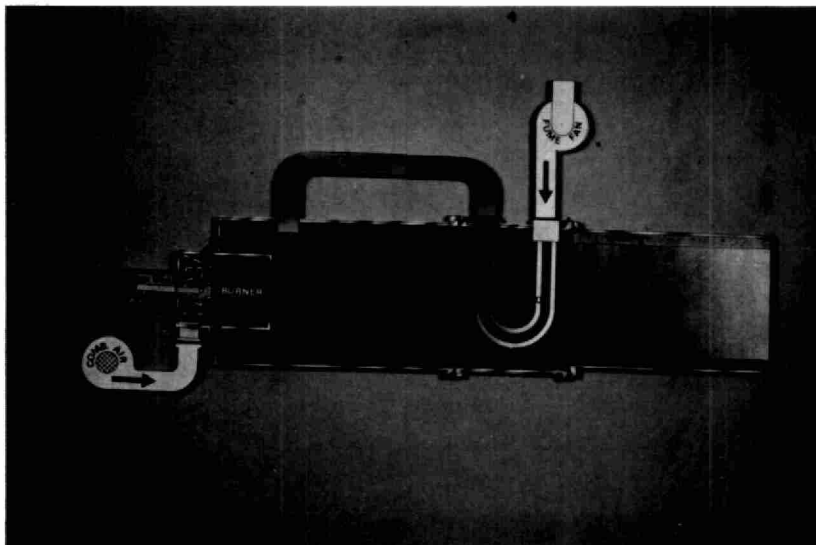


Fig.15 - Fume Incinerator  
with Preheating Section





## "VERMILION DAM - A ROCKFILL DAM TO STORE MINE TAILINGS"

BY

J. O. OSTERBERG

PROFESSOR OF CIVIL ENGINEERING

NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS.

### Introduction

I am pleased to appear at the 15th Ontario Industrial Waste Conference to tell you about a most interesting project with which I have been associated for about three years. I am referring to the Sherman Mine project located only a few miles from the town of Timagami, 300 miles directly north of Toronto. The Sherman Mine is a joint venture of Dominion Foundries and Steel Company Ltd., of Hamilton and Tetapaga Mining Company, a wholly owned subsidiary of The Cleveland Cliffs Iron Company. The operation consists of open pit mining of magnetic taconite iron formation from a north, south and west pit, all located within a few miles of the pellet plant where the ore is processed for shipment. Operation of the plant was started in January of this year, and it is expected that 1,000,000 tons of high grade iron ore pellets will be the annual capacity.

A number of factors combine to make these low grade crude ore bodies economical for production. The most important factor is the concentrating and pelletizing

process which processes the ore containing some 20 to 25 per cent iron to produce pellets with 63 per cent iron. This process alone would not make these ore bodies worthwhile if it were not for the location close to the Ontario Northland Railroad, close to the Trans Canada pipeline and readily available inexpensive electric power. Lastly the project would not be possible if it were not for a plentiful supply of water.

In producing the pellets, large quantities of mine tailings must be disposed of, and for this a rockfill dam 160 feet high from its lowest point and containing about 1,200,000 cubic yards was designed by the writer. The writer also was involved in the site exploration and advised on the general supervision of the construction of the dam. This paper, therefore, will describe the construction of the dam, the water circulation and re-use scheme developed, and the steps taken to avoid pollution to the nearby Lake Timagami, a very large lake and a great resort area.

### Mining and Producing Pellets

Before the mines can be put in operation, a great deal of rock must first be stripped. During the stripping operations, the rock was used to make haul roads and for the construction of the large dam hereafter called Vermilion Dam. With the completion of Vermilion Dam last fall and the beginning of the operations at the pellet plant in January, the ore is hauled from the north pit, west pit and south pit, to the pellet plant site shown in Figure 1. At the plant the ore is dumped into a large gyratory crusher which reduces the large chunks of ore to -9 inches. The crushed ore is then conveyed to the plant or the surge pile for later reclaiming. In the plant itself the ore is put through a grinding process which grinds the ore to finer than face powder, -325 mesh size by a series of grinding operations. The first step is the autogenous grinding mills which are currently the largest ever made. Leaving the autogenous grinding mills with a 2-1/2 inch maximum size, the ore is then ground further through a series of operations until the face powder in size ore is mixed with water and transported as a slurry. While flowing through troughs, magnetic separators separate the magnetite iron from the other material which is then de-watered and then with a small amount of bentonite added rolled into pellets smaller than 1/2 inch size. The pellets are then heat hardened in a grate kiln at 2400° F to make them firm and hard. After cooling, the pellets are loaded directly into railroad cars for transportation to Hamilton.

The tailings remaining after the magnetite ore is separated from it consisting largely of silica, is a waste for which no known economic use has been found. The tailings are thickened and the water is clarified and reclaimed for use in a 200 ft. diameter tailings thickener. The remaining tailings are then pumped for disposal. Thus at a production rate of 1,000,000 tons a year, the waste is being produced at almost 2,500,000 tons a year. To store these tailings, it is pumped by pipeline to Vermilion Lake shown in Figure 1. But in order to reclaim the water as well as retain the tailings and to be able to operate deeply at the north pit at the south end of Vermilion Lake, it was necessary to construct Vermilion Dam. With the dam in place, it is then possible to pump the tailings into the reservoir behind the dam with the spillway discharging the excess water into the small lake shown just north of O'Connor Lake, and then by a small connecting channel to O'Connor Lake. This is shown in Figure 2. From O'Connor Lake to Vermilion Creek which connects Vermilion Lake with Tetapaga Lake a channel had to be constructed which was largely blasted out of rock. Just north of this channel and south of north pit, a small dam was constructed to keep the water from returning to the south end of Vermilion Lake and interfere with the north pit operations. From the east end of Tetapaga Lake the water is pumped to the pellet plant for the slurry operations. Figure 2 shows the water circulation scheme with heavy black lines. It is seen that the water is constantly being re-used, passing through the several lakes in the process. The cycle is self-contained and because there is a slight excess of water falling as rain over the watershed, this excess flows from Tetapaga Lake through a creek into Lake Timagami. At the junction of Tetapaga Lake and the creek is a small weir in which the level of Lake Tetapaga can be controlled within a few feet. Thus the water from the initial tailings basin goes through 1, 2, 3 supplementary settling basins before returning to the plant and before any excess water is diverted to Lake Timagami. Thus clarification of the water is complete. At other operations at plants owned by Cleveland Cliffs Iron Company in northern Michigan, complete clarification is being achieved with only one settling basin after the discharge of the water from the primary tailings pond. Complete clarification of the water will be maintained at all times. As a matter of fact, during the construction of the dam, when it was necessary to lower the level of Lake Vermilion and to completely de-water the south end, the water was pumped through the same circuit without the benefit of the primary settling basin. Also this water contained much finer silts and clays as well as organic matter, and yet full clarification was obtained. It is rather fortunate that at this site the lakes were so situated that it was possible to have the three settling basins for the spillway discharge.

## Design of Dam

The dam crossing Vermilion Lake will be over one-half mile long when completed to its final height. The first stage of the dam to elevation 1030 has now been completed, and in five years the height will be raised another 50 feet. Referring back to Figure 1, during this first period the area to the north-east of the dam will be filled with tailings. Then when the north pit is mined out, the first to be depleted, it will be filled in with tailings to elevation 1020 when the dam will have been raised to elevation 1080. Then additional tailings will be stored to the northeast to elevation 1075. Thus after a 30-year period there will be a flat land of tailings 50 feet higher on the northeast side of the dam than on the southwest side. The next figure shows the cross-section of the dam at its largest cross-section. This cross-section is along Vermilion Lake which originally was about 35 feet deep. The lake as seen is a long narrow lake extending along a geologic fault. On the east shore the slope is almost everywhere bed-rock dipping steeply into the lake. On the west shore the bottom of the lake and the land above slopes more gently. The bottom of the lake is filled with 20 feet of very soft organic silt at its deepest point. Handling this silt presented a problem, but with the method conceived, the organic silt was handled successfully. Shown in the next figure is a cross-section of the dam showing the initial portion and the final portion, together with the upstream and downstream cofferdams. Because it was necessary to raise the dam 50 feet after tailings would be stored against the upstream slope of the initial dam, it was necessary to design the impervious core and adjoining sand filters sloping downstream as shown.

Figures 3 - 8 illustrate the construction sequence. Figure 3 shows the soil conditions before construction and the natural level of Lake Vermilion at 994. Under the soft black organic silt (ooze) is a very compact and hard gray till. This gray till is a fine silt with some boulders and is extremely dense and hard. The lake level was initially lowered some 14 feet by simply cleaning out Vermilion Creek of its debris and deepening the channel. Then the water was pumped by two 10,000 gallon per minute submersible pumps to about elevation 970. During this final pumping two rockfill coffer dams were constructed by end-dumping the rock from the stripping operation at the three pits. This dumping of the rock displaced the organic silt approximately as shown on Figure 4. After the coffer dams were in place a hydraulic dredge was used to pump the silt from between the coffer dams, depositing it on the north side of the upstream coffer dam. When all the silt was pumped out from between the coffer dams, pumping was continued downstream to completely drain the south portion of Vermilion Lake and excavation was continued to bedrock along the impervious core section (Figure 5). When the rock was exposed across the dam at the impervious core section, the core section (Figure 6) was placed with the filter material on both sides.

The core material was the gray glacial till material found largely along the lake shore after the lake was lowered. The purpose of the core is to prevent the seepage of water through the dam and the purpose of the filter is to prevent the core from eroding into the large voids of the rock. The filter consisted of selected sand and gravel found around the site. In order to avoid a drastic transition from the sand and gravel to the large size dumped rock, a transition section of finer rock with rock dust and fines selected from the mine stripping was placed next to the sand filters. Shown in Figure 7 is the dam finished to its present height with water and mine tailings stored behind it. Figure 8 shows the dam built 50 feet higher with the ultimate storage with mine tailings on both sides. With this plan in mind I will then discuss the actual construction of the dam.

### Construction of Dam

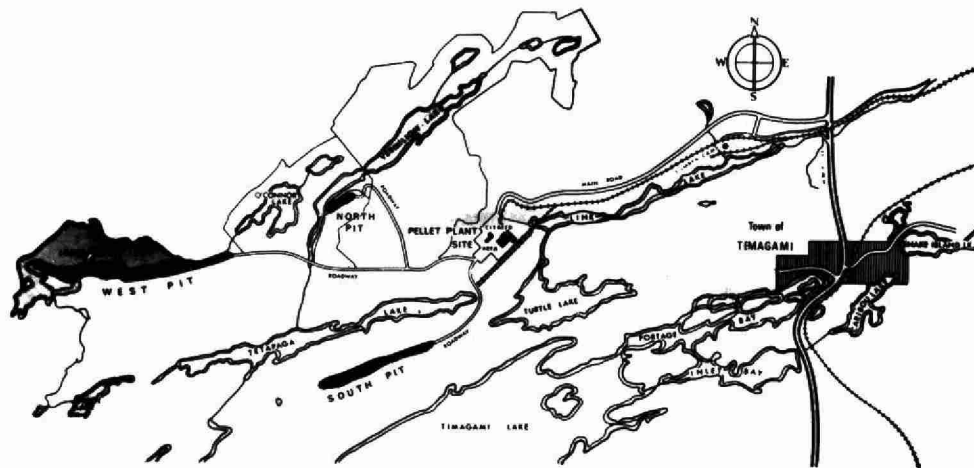
During the construction of the dam, we were most fortunate with Mother Nature from several viewpoints. First, we had excellent weather, especially during the crucial period of construction, namely when we reached the very bottom and during the period of the placement of the impervious core. We were also lucky in that we were able to find sufficiently close by enough impervious material to make an excellent compacted core. We were also able to find a suitable sand and gravel for the filter material. There are many parts of the north country in which impervious fill is virtually non-existent and where one has to transport sand and gravel rather long distances.

The optimum moisture content for placing the core material at the maximum density was about 8 per cent which was also about the natural moisture content of the soil. Thus it was not necessary to either dry the soil or wet it, provided it was placed immediately after it was transported from the borrow pit. When placed at this moisture content, we obtained very excellent densities, sometimes as high as 145 lbs/cubic foot. However, as soon as it rained, this fine silt became a muddy mess, and work had to be halted. However, by anticipating rain and crowning the core material so it shed its water, only a very thin layer became soft provided traffic was kept off it during and shortly after rain. It was then possible to get back on to the core material rather quickly and continue work.

It has been a pleasure for me to present this paper to you, and indeed a pleasure to be connected with such an interesting project. Thank you.

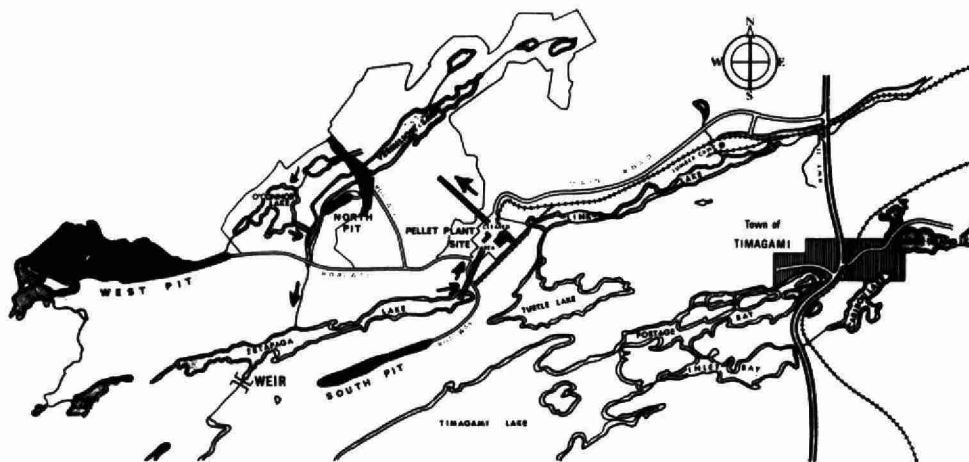


Figure 1



*A sketch of the Sherman Mine properties showing the major features and also the location of the mine with respect to the Town of Temagami.*

Figure 2



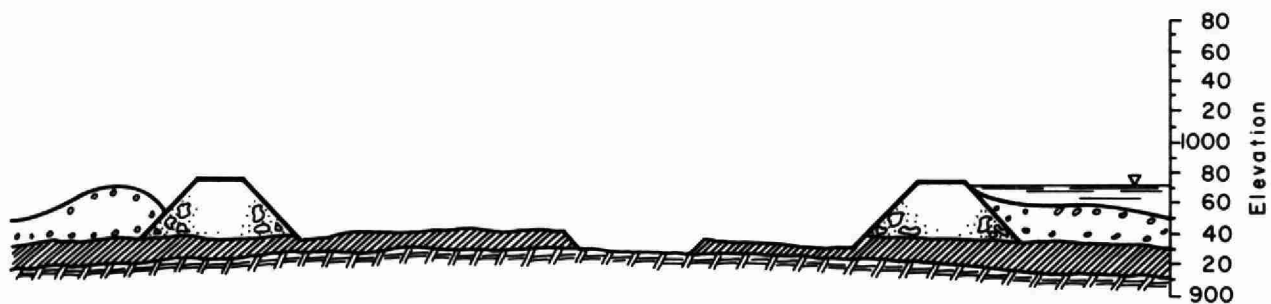


FIG. 2

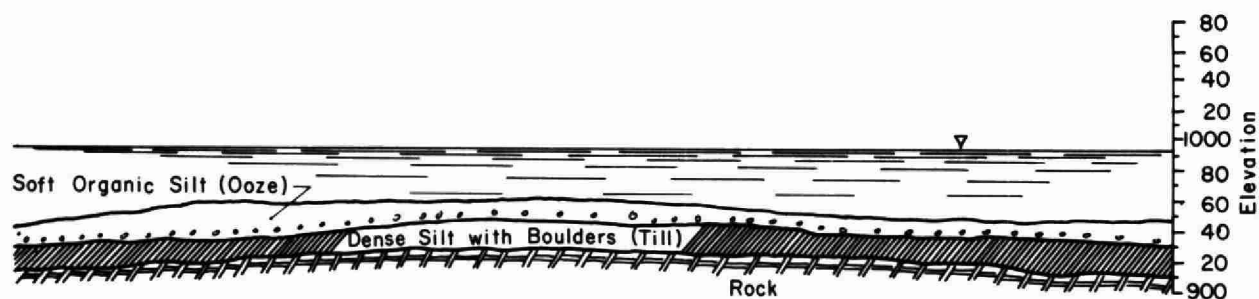


FIG. 3

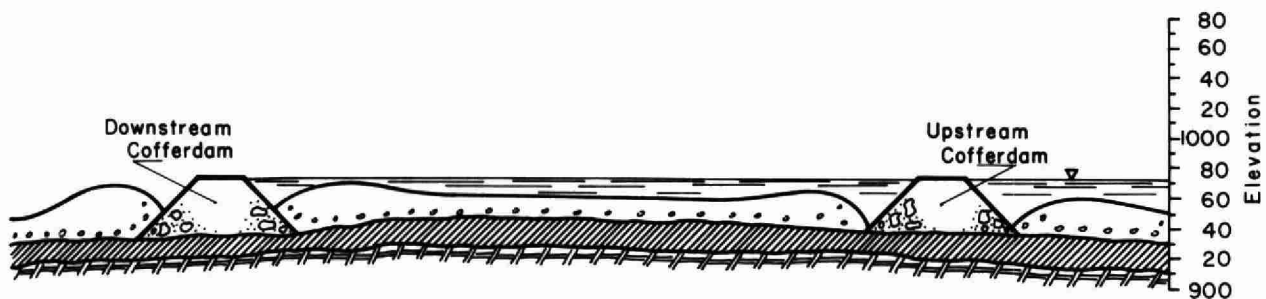


FIG. 4

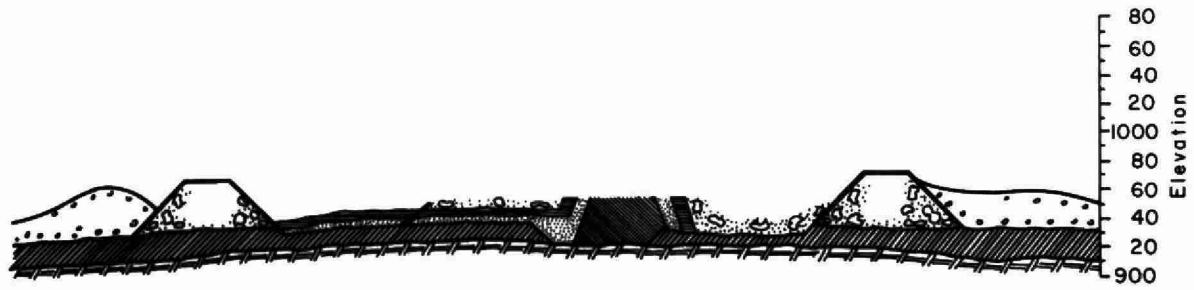


FIG. 6

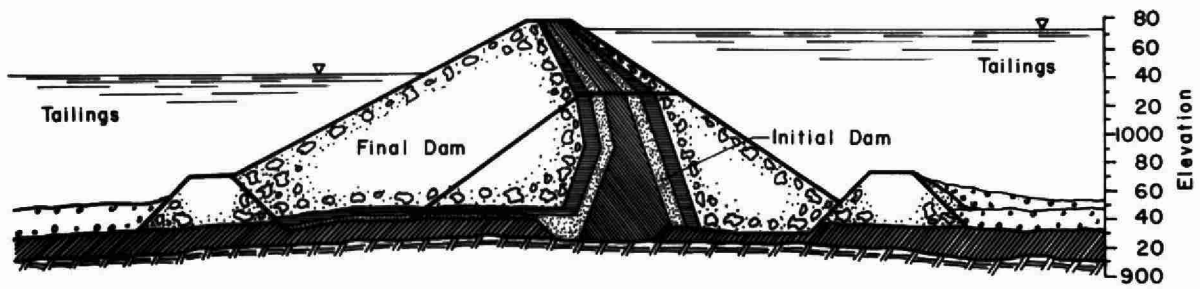


FIG. 8

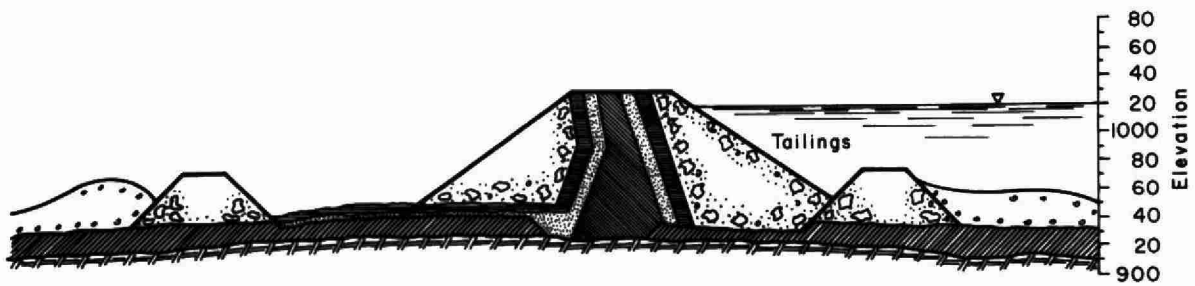


FIG. 7



"THE USE OF VEGETATION TO STABILIZE MINE  
TAILINGS AREAS AT COPPER CLIFF, ONTARIO"

BY



T. H. PETERS  
ASSISTANT AGRICULTURALIST

C. A. YOUNG  
AGRICULTURIST  
INTERNATIONAL NICKEL CO. OF CANADA LTD.,  
COPPER CLIFF, ONTARIO.

The stabilization of tailings has been a matter of concern to the mining industry for many years. In earlier times, when mines were small and only high grade ore deposits were mined, the problem was not a great one. But, more recently - during the last 30 to 40 years - the increased world demand for various metals, combined with the vast strides that have been made in the improvement of metallurgical extraction processes, have resulted in the development of lower grade ore bodies. To be specific, ores containing as little as 1% metal are now being mined, which, on a per ton of ore basis means that there are only 20 pounds of metal present, the remainder being extraneous material.

As I am not sure how familiar all of you are with the mining industry I will, if I may, digress for a few moments from the main theme of my address. In Ontario, the mining industry celebrated Canada's Centennial by exceeding for

the first time, the billion dollar mark in total value of minerals produced in 1967. This represents approximately 27.11% of the value of Canadian Mineral production for this year and if fuel is omitted, 37.89%.

One of the contributors to this achievement was the International Nickel Company of Canada, which at present operates in its Ontario Division nine mines, two open pits, four mills, two smelters, an Iron Ore Recovery Plant and a Copper Refinery in the Sudbury area, as well as a Nickel Refinery at Port Colborne. In Ontario, the Company has over 20,000 employees of whom more than 18,000 are in the Sudbury area. In addition to this, there are 6 new mines in various stages of development in Ontario, as well, of course, as the established nickel producing complex at Thompson, Manitoba.

The waste product of the Mills mentioned above is "tailings" which are the barren rock particles removed from the ore through a system of crushing, pulverizing and flotation. Some tailings are returned underground for use as mine fill, and the remainder is mixed with water and pumped out as a slurry through large diameter pipelines to the disposal areas. Tailings have the texture of fine beach sand and are composed mainly of silica along with some iron, calcium, magnesium etc. It might be of interest to you, that our milling capacity is 64,000 tons per day of feed and that some 48,000 tons of tailings must be disposed of daily. The tailings are distributed from pipes around the perimeter of the disposal area, resulting in a saucer shaped development i.e. a low centre with a higher outside rim.

About 30 years ago, the Company started experiments to stabilize the surface of the tailings and prevent them from becoming a dust source under certain weather conditions. The use of chemicals to form seals, covering with crushed stone, mulching with straw and some early seedings were some of the stabilizing methods tried. Results were either unsuccessful or impractical economically.

But, no matter how unsuccessful a particular scheme turned out, the attempt to find a solution was never written off. As we look back, we realize that the first significant break-through came as the result of three test plots planted in the Spring of 1957. Each plot covered an area of approximately one-third of an acre. One plot was successful and persisted until it was covered up by the expansion of the tailings area in 1961.

A slightly larger plot was planted in early August, 1958, but much to our dismay, the seed remained dormant during 1958 and until the late summer of 1959, when a few seeds germinated. At this time, it was presumed that the seed had blown away, had been eaten by birds or had been covered too deeply by the drifting tailings.

However, in 1960, as a dust control measure, a larger than normal pond was maintained in the tailings area which increased the height of the water table. Along with this, the precipitation for the months of May, June and July was above normal. Much to our surprise, the seed which had been planted in this area in 1958 began to germinate. Grass from this seeding is still present today.

A searching appraisal was made at this time by the members of the Agricultural Department on the practices we had used and the success attained. It was true that we could grow grass on tailings but successfully only 50% of the time. We found that the seed would germinate but the young plants would either be cut off or buried by the drifting tailings. The one 1957 plot that had been successful was near a pond and on the southwest corner of the area. In the case of the 1958 seeding, the high water table coupled with the above normal precipitation had reduced the drifting of tailings when the 1958 seeding germinated in 1960 until the seedlings were established.

The three factors which emerged from this review that we felt would increase the success of our seedings were:

1. The seedings should be made in a location as close as possible to the edge of the tailings area from which the prevailing wind picked up tailings which buried or blasted the young plants.
2. A companion or nurse crop should be used to provide cover for the young seedlings, or snow fencing erected to reduce wind velocity in exposed areas.
3. The amount of plant nutrients and their availability should be increased by stepping up our rate of fertilizer application and by applying agricultural lime-stone sufficiently in advance

of seeding to permit the pH of the area to approach the neutral zone.

The pH of old tailings is generally acid, due to the oxidation of sulphides in the tailings to sulphates and thiosulphates. This low pH reduces the availability of plant nutrients.

In June, 1960, a plot 800' x 30' was planted alongside the 1958 planting, using snow fence along one side for protection, and with an increase in the rate of the fertilizer application. The effect of water table was also studied, as there was a slight ascending rise through the length of the plot. The success of this seeding was evident in early July and plans were made for the seeding of a larger area later in the summer.

As the prevailing summer winds at Copper Cliff are from the south-west, a two acre plot in the south-west corner of the "C" area was laid out. Agricultural limestone was applied at the rate of two tons per acre on July 22nd.

On September 8th, three tons of agricultural limestone per acre and 1,600 lbs. of 4-12-10 fertilizer per acre were spread and disced into the tailings. On September 9th the plot was seeded, using a conventional farm seed drill with a grass seed attachment. The fertilizer, 4-12-10, was applied at the rate of 400 lbs. per acre. The companion crop of Fall Rye was seeded at the rate of one bushel per acre along with grass seed at the rate of  $37\frac{1}{2}$  lbs. per acre through the drill. Brome grass was broadcast by hand immediately after the seeding and covered by a plank drag.

Germination of both rye and grass was excellent and this plot went into the winter in very good shape.

At the same time, September 8 and 9, an additional 15 acres alongside this plot was treated with agricultural limestone at the rate of three tons per acre, for seeding in the Spring of 1961.

The two acre plot was fertilized in the Spring of 1961 with three types of nitrogen fertilizers on different strips. The rye produced eight bags (16 bushels)

of grain when combined and the grass is still well established.

The 15 acre plot known as plot 7, the largest tried to-date, was limed on May 3, 4 and 5 with limestone at the rate of two tons per acre, and disced. On May 6, 600 lbs. of 6-12-12 fertilizer was spread and harrowed in. Seeding was carried out on May 11 and 12, using a seed drill and the following mixture was used per acre:

- 12½ lbs. - mixed grass seed
- 12½ lbs. - Canada Blue Grass seed
- 10 lbs. - Alfalfa or,
- 10 lbs. - Sweet Clover
- 1½ Bushels of oats

Eight lbs. of Brome Grass Seed was broadcast after the seed drill had seeded the area. Four hundred lbs. of 6-12-12 fertilizer was applied by the drill when seeding.

The two legumes, alfalfa and sweet clover, were used on different areas. Previous work had shown that Sweet Clover was successful for one or two years only while reports of the successful work done on tailings in South Africa with Alfalfa (lucerne as they call it) warranted our investigation of its suitability for our area. It has persisted in this plot to this day.

This plot grew well during the summer and the oats when harvested produced 25 bushels per acre.

Additional spring seedings on plots of one acre each were carried out on non-previously limed tailings, using hydrated lime as a more rapid method of adjusting the tailing's pH, and using the same seeding procedure mentioned above. They also proved successful though more costly, but can be used when time is the limiting factor.

The sight of a combine cutting the grain gave us a good deal of satisfaction. Care was taken while combining to leave a 10" to 12" stubble to trap the snow of the following winter, to ensure moisture for growth the following year.

The successful wintering of the two-acre plot and the early growth of the 15-acre plot

indicated we were on the right path. The time had come to test this program on a larger scale.

In May, 1961 a 100-acre block at the west end of our tailings area "C" was laid out and a preliminary liming carried out in early June. Liming, fertilizing and seeding using the method and rates outlined, were carried out in the first three weeks of August. This plot grew well and it was interesting to note that the growth in first seeded areas was more vigorous than in the latter seeded areas. This prompted us to advance our seeding commencement date to about July 20 from that time on. During the fall, deer, geese and ducks were observed on numerous occasions pasturing on the rye and young grass. The amount of seed the various birds eat after planting necessitates a heavier than normal farm seeding.

A further step in large area seeding was undertaken in September and October with the preliminary liming for 1962 seeding of an additional 160 acres, at the rate of three tons per acre.

The way the grass stands survived the summer of 1962, with its prolonged period of hot weather and drought, was to further prove that we were on the right road in using grass to stabilize the tailings. But, it was also to show that the road to success was not smooth.

In an effort to get more of the "C" area under grass, 66 acres were seeded by May 17, using oats as a companion crop. Although temperatures were normal for the early summer months, with the exception of May which was  $5.4^{\circ}$  above average, precipitation was much below normal. Until June 20 the growth was good, but from there on the effect of the drought became increasingly evident. On July 5 it was decided to cut the oats in an attempt to preserve the soil moisture for the grass seedlings by reducing transpiration loss. It was necessary to reseed about half of this area in August along with the remaining 100 acres that had been limed.

As mentioned, the seedings of the previous years survived the drought in a most satisfactory manner. Sufficient grain (rye) was harvested for the fall seeding and over \$800. worth was sold.



At this time, I would like to point out we had largely completed the seeding of the "C" area and had made some preliminary tests with the tailings in the newer "M" area, which was beginning to reach its final level. I should also add that the Company's Special Project Department was carrying out experiments in other methods of dust control during this period.

The tailings in the "M" area have a different makeup than those in the "C" area in that they contain less iron. A process developed by INCo's research staff for the recovery of iron included the extraction of an iron-rich concentrate in the milling process.

The "M" area is closer to the Town of Copper Cliff and the Copper Refinery, increasing the inconvenience caused by blowing dust. With the extraction of the iron, the tailings had less of a tendency to form an oxidized surface layer and therefore were more prone to remain loose and thus a greater potential source of dust. Our Special Projects Department had developed an irrigation system which kept the major dust source area moistened down by a timed rotational program of sprinkling. This system worked on a 24-hour-day basis.

With this irrigation available, a spring seeding was deemed a good risk and was undertaken and completed by May 13. The oats germinated in time to be covered with snow and ice from the sprinklers as a result of a cold night on May 22. Growth was very poor in the area close to the sprinklers. Measurements taken indicated that the plants in close proximity to the sprinklers were getting the equivalent of three inches of precipitation every 24 hours. We had gone to the other extreme - we were drowning them with kindness. The control of the sprinklers was turned over to the Agricultural Department of the Special Project Department, and a more realistic program of irrigation to sustain plant growth was carried out.

In 1964, an area located in the south-west corner along the inside crest of the south dam was ready for seeding. After the dry summers of the past two years it was decided to take a calculated risk on the chance of higher than average early summer precipitation, and try a spring seeding. However,

drought conditions persisted, and even a crash irrigation program failed to make this seeding successful.

This failure in an area so exposed to the prevailing winds indicated the necessity of stabilizing the tailings in some manner until the seed could germinate and the plants become established. Two methods of mulching were considered. Both were the same in principle but one used straw as the cover while the other used wood fibre or pulp. Both used a bitumen compound as a binder. In the end the wood fibre method was selected.

Early in August the area was limed, using bulk limestone for the first time, and disced in. Some of the fertilizer and rye was spread and harrowed in. The remainder of the seeding was done by the Sprayturf Company under contract. Their seeding equipment consists of a standard truck chassis with an extra set of dual wheels. On this chassis and 1800-gallon tank is mounted, along with a smaller 200-gallon tank which contains the bitumous binding compound. Baffles and paddles powered by a separate motor are installed in the large tank to mix and maintain the materials in suspension as a slurry. This motor also powers the pumps which take the slurry from the tank to the nozzles mounted on the top and rear of the tank.

In operation, the wood pulp fibre (1,000 lbs.) was fed by hand into the large 1800-gallon tank along with 25 gallons of the bitumous compound. When the main tank was nearly full, 600 lbs. of 8-16-16 fertilizer, 25 lbs. of grass seed and 10 lbs. of Brome grass were added. This was enough to seed one acre. The slurry was continuously agitated while the truck was driven to the area to be seeded.

Two operators on the top of the tank manipulated the nozzles as required to obtain an even coverage of the ground with the mixture.

Our work continues, but, I think you can gather from what I have already said that the stabilizing of tailings with vegetation has been beset by problems of different kinds from time to time. There are now well over 500 acres of grass established on tailings. We have evolved a fairly standard program which we use



to establish and maintain these areas, which I will outline.

In fact, the steps I outline will be the procedure we will use to grass an additional 60 to 70 acres this year.

About the first of June, feed grade limestone was applied at the rate of three tons per acre and disced in. The feed grade limestone is a little coarser grind than the regular agricultural limestone and therefore will break down more slowly and have a longer pH buffering period.

Around July 10, agricultural limestone will be applied at the rate of two tons per acre and will be followed with an application of 5-20-20 fertilizer at the rate of 400 lbs. per acre after which the ground will be harrowed. You will note that we have stepped up the fertilizer analysis to 5-20-20 and reduced the rate of weight application from that mentioned earlier. Higher analysis fertilizers provide plant nutrients at a lower cost per unit and, by increasing the total nutrient per hundred pounds of fertilizer, reduce our handling costs.

Seeding will commence on July 22, if all goes well, and the same fertilizer will be applied at the rate of 300 pounds per acre. Fall rye, which was harvested from our tailings last year, will be used at the rate of  $1\frac{1}{2}$  bushels per acre. A Massey Ferguson Model 26A, 13 run seed drill will be used with two grass seed attachments.

The grass seed mixture will be made up of the following varieties and proportions.

- 12½ lbs. Canada Blue Grass
- 12½ lbs. Mixed Seed
  - 1 Part Timothy
  - 2 Parts Red Top
  - 1 Part Kentucky Blue
  - 1 Part Crested Wheat
  - 1 Part Creeping Red Fescue

Immediately after this seeding, Brome Grass will be seeded at the rate of 10 pounds per acre from a tractor-mounted Alvan Blanch Seeder. A cultipacker

will follow to press the Brome seed into the top of the tailings and generally firm the seed bed. Germination will take about 10 days.

Once grass has been established, annual maintenance practices must be carried out. Urea at the rate of 100 pounds per acre is applied each fall after freeze-up and immediately after cutting in June or July, two hundred pounds per acre of 5-20-20 fertilizer is broadcast using a Lely spreader.

I mentioned cutting. We have been cutting and selling hay off these areas for the past four years and the hay has been fed to all classes of livestock. Last year, somewhat over 7,000 bales of hay were sold for a return of over \$3,400.

One interesting development is the volunteer establishment over recent years of trees, principally birch, in the grassed areas.

Experiments designed to find better practices and lower costs are continuing. At present, we are looking at still higher analysis fertilizers, the lowering of competition between the companion crop and the grass seedlings, and the establishment of legumes.

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ONTARIO WATER RESOURCES COMMISSION



"PILOT PLANT STUDIES ON COMBINED DOMESTIC  
AND PAPER MILL WASTES"

BY

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SECTION I - INTRODUCTION

This paper presents the results of pilot plant studies undertaken to determine process design parameters for the treatment of combined, domestic and paper mill wastes in the City of Plattsburgh, New York.

Plattsburgh is located in the northeastern corner of New York State, along the shores of Lake Champlain at the mouth of the Saranac River.

The main catalyst in bringing about a joint waste treatment study was the New York State Pure Waters Program. This program, financed by a billion dollar bond issue, is a massive effort to provide an adequate degree of treatment for all pollution sources in the state by 1972. The main incentive in this program, aimed primarily at municipally owned, operated and constructed facilities, is a 60% capital construction grant.

Early in 1965 the industries in the City of Plattsburgh, consisting of the three large paper mills, approached the City concerning the feasibility of joint waste treatment. The first step in the program was a

feasibility study outlining the required degree of treatment and approximate estimates of cost. The second step in the program was the pilot plant study reported herein.

With the inception of the New York State Pure Waters Program, the degree of treatment required prior to discharge of municipal and industrial wastes has been substantially upgraded.

Under present policies and programs, all waste discharges will have to receive secondary treatment, which by Health Department determination in Plattsburgh was 85% reduction in BOD and suspended solids.

The scope of the present studies is to determine design parameters for a treatment method which will produce an effluent with a minimum of 85% BOD and suspended solids removal for the combined waste flow from the City and industries.

Several secondary treatment processes are available by which an 85% BOD reduction might be obtained. Among these are activated sludge and its various modifications, two stage trickling filters, aerated lagoons and oxidation ponds.

The treatment plant site is a City-owned island at the mouth of the Saranac River. This island is utilized by the existing City primary treatment plant and the municipal power facilities.

During the preliminary investigation, trickling filters and aerated lagoons and/or oxidation ponds were not considered because of the space limitations on the present site. The pilot plant studies concentrated on the activated sludge process and its modifications.

## SECTION 2 - WASTE WATER SOURCES AND FLOWS

In order to insure that the pilot plant operation would closely duplicate the anticipated full-scale facilities, the waste from the various sources had to be blended in proportion to the flow from that source. The pilot plant studies were based on the present average daily flow from each source and no allowance was made for any proposed in-plant changes to reduce the volume of waste from the mills.

Table 1 indicates the wastewater flows and distribution thereof from the City and the three mills at the time of the pilot plant studies. The raw waste flow from the City is ordinary domestic sewage. However, the dining halls of the State University and a large number of hotels, motels and restaurants catering to the tourist trade produce a substantial grease load at the existing City primary treatment plant.

Mill No. 1 is a ground wood mill, manufacturing molded fiber containers. Two major waste streams flow from this mill. They are noted as the pulping and barking and plain molding departments, and the steam plant and duplex operation.

Mill No. 2 is a tissue mill with a sulfite pulping operation. The "press effluent" is essentially the waste cooking liquor from the digester and the thickener overflow is a dilute mixture of waste cooking liquor and wash water after the first stage refining of the digested wood.

Mill No. 3 produces wall paper from ground wood pulp. There are two main waste streams. One from the pulping and papermaking operation and the second from the wall paper operation consisting of washings, dyes, coatings and pigments.

The discharge of cooking liquor from Mill #2 presented some special problems. This discharge, referred to in Table 1 as the "press effluent" is only 1% of the total flow, however, it contains approximately 50% of the organic loading. At the inception of the study there was some question on the part of Mill #2 about the economics involved if the company were to treat the "press effluent" waste stream separately and not discharge this stream to the municipal system. The preliminary laboratory studies and pilot plant program were designed to operate both with and without the "press effluent".

The volume and the size of the treatment plant units would not be substantially affected if the press effluent were included or treated separately. However, the operating cost in terms of power and the basic process selection itself could be affected depending upon the inclusion or exclusion of the "press effluent".

The industrial waste from the paper mills contains substantial amounts of suspended solids in the form of wood fibres and clay filler material. Experience has indicated that large amounts of fibrous material will interfere in the biological oxidation process by becoming matted with the activated sludge. For this reason, primary settling was used as pretreatment during the pilot plant studies.

TABLE 1  
WASTE WATER FLOWS  
AND DISTRIBUTION

<u>Source</u>	<u>Avg. Daily Flow MGD</u>	<u>% of Total</u>
<u>City</u>	5.0	32.40
<u>Mill #1</u>		
Pulp, Bark & Plain Molding	0.87	5.63
Steam Plant & Duplex	0.43	2.80
<u>Mill #2</u>		
Paper Plant	5.40	35.00
Press Effluent	0.14	0.90
Thickener Overflow	0.61	3.95
<u>Mill #3</u>		
Wall Paper Production	0.08	0.52
Pulping & Paper Mill	2.90	18.80
Total	15.43	100.00

### SECTION 3 - LABORATORY AND PILOT PLANT STUDIES

#### A. Laboratory Studies

In order to determine the combined waste characteristics and the effectiveness of biological treatment, laboratory studies were conducted prior to pilot plant operations.

Samples were blended in the proportions indicated in Table 1, and the results are shown in Table 2.

TABLE 2

#### LABORATORY DATA

#### AVERAGE WASTE CHARACTERISTICS

<u>Sample</u>	<u>BOD</u>	<u>SS</u>
Combined waste with "press effluent"	411	459
Combined waste without "press effluent"	180	444

1.5 liter laboratory biological oxidation cells were established and seeded with activated sludge. The cells were fed daily on a batch basis for one week. After that, time samples were withdrawn at intervals after each feeding. The results of a batch oxidation run are shown in Table 3.

The batch oxidation studies indicated that the waste with and without "press effluent" was amenable to biological treatment and that an effluent low in BOD could

TABLE 3  
LABORATORY - BATCH  
BIOLOGICAL OXIDATION DATA

A. With "Press Effluent" - Avg. Mixed Liquor Suspended Solids 1241 mg/l

<u>Time Hours</u>	<u>Remaining BOD mg/l</u>
0	285
1/2	165
1	127
6	22

B. Without "Press Effluent" - Avg. Mixed Liquor Suspended Solids 2064 mg/l

<u>Time Hours</u>	<u>Remaining BOD mg/l</u>
0	81
1/2	68
1	42
6	22

All necessary equipment for the setting up of the pilot plant and for the analytical work was shipped to Plattsburgh. Actual pilot plant operations and analytical work was performed by O'Brien & Gere personnel.

Each waste source was sampled once daily. The paper mills are continuous operations and the waste streams are relatively constant except during washup and changeover periods. The sample of the City domestic waste was taken each morning. However, the largest single flow, Mill #2 Paper Plant, was collected as a daily composite sample.

A schematic diagram of the conventional activated sludge system used in the first phase of the pilot plant studies is shown in Figure 1. The raw waste was pumped from the feed tank through the primary settling tank from where it flowed by gravity into the aeration tank and at that point the return activated sludge from the secondary clarifier joined the waste stream. After undergoing 6 hours of



biological oxidation in the aeration tank, the flow proceeded by gravity to the final settling tank where the activated sludge was removed through sedimentation and returned to the aeration tank. Waste activated sludge and primary sludge were withdrawn at the discharge points indicated on Figure 1. The clarified effluent from the secondary settling tank was then discharged to an effluent collection drum. The raw waste flow was 45 ml/min. (17 gal/day) and the return sludge rate was 15 ml/min. (33% return).

Small air compressors which supplied oxygen for the biological oxidation and mixing of the aeration tank contents are not shown in the diagram but were part of the system. Sufficient air was supplied to maintain an excess of dissolved oxygen in the system at all times.

#### C. Pilot Plant Procedure - Contact Stabilization.

In addition to conventional activated sludge, a modification of this process known as contact stabilization was also investigated. In this modification, return activated sludge is mixed with the raw waste for a short period of contact and then separated by sedimentation. The return sludge from the secondary settling tank is aerated separately before being returned to mix again with the raw waste. This modification, if applicable, permits the use of smaller aeration tank volume by utilizing the initial removal capacity of stabilized sludge. The schematic layout of contact stabilization is shown in Figure 2.

Contact stabilization was evaluated over a wide range of loadings and detention times both with and without the "press effluent" from Mill #2. The basic purpose of this portion of the study was to determine if the "press effluent" would have any effect of a basic selection of the treatment process.

#### D. Pilot Plant Results - Activated Sludge.

In Figure 3, the BOD value of the raw waste in milligrams per liter is plotted against its probability of occurrence. The distribution is plotted as a normal distribution with a means or 50% value of 429 mg/l. Figure 4 represents the same plotting procedure for the suspended solids content of the raw waste indicating a mean value of 320 mg/l.

As mentioned previously in this paper, primary settling was used throughout the entire period of the pilot plant study. The performance of the primary settling tank averaged 26% BOD removal and 55% suspended solids removal. The primary sludge withdrawn from the clarifier was approximately 1.1% of the total plant flow, and contained approximately 1.25% solids by weight.

Figures 5 through 8 indicate the performance of the conventional activated sludge pilot plant.

Figure 5 represents the over all performance of the activated sludge phase of the studies. The pounds of BOD applied per pound of mixed liquor suspended solids in the aeration tank was plotted against the pounds of BOD removed per pound of mixed liquor suspended solids. The slope of this line represents the per cent. removal of BOD applied to the aeration tank and indicates the over all performance of the aeration tank as 88% removal of the BOD applied.

Figure 6 presents data on total sludge production from the activated sludge phase of the studies. From this data the sludge production per unit of BOD removal appears high. This may be due to carryover of the fine fibrous material from the primary settling tank. This material is removed with the activated sludge in the secondary settling tank and is measured as waste secondary sludge.

Figure 7 represents the oxygen utilized by the organisms composing the activated sludge during the oxidation of the organic matter in the aeration tank. The total amount of oxygen required is expressed as a function of the amount of the organic material removed and as a function of the total mass of activated sludge in the aeration tank. The information contained in Figure 7 is necessary to properly size aeration equipment for adequate oxygen transfer to sustain the activated sludge process.

Figure 8 presents the over all percentage of BOD reduction of the complete activated sludge process including primary sedimentation. The percent reduction is indicated as a function of the raw BOD applied per pound of suspended solids in the aeration tank; and as indicated in Figure 8, BOD reduction in excess of 90% can be expected when the loading on the aeration tank is kept below approximately 0.7 pounds of raw BOD applied per pound of sludge under aeration.

#### E. Pilot Plant Results - Contact Stabilization.

Table 4 summarizes the results of the contact stabilization portion of the pilot plant studies.

TABLE 4  
CONTACT STABILIZATION  
PILOT PLANT PERFORMANCE

<u>Waste Source</u>	<u>Contact Time</u>	<u>Stabil- ization Time</u>	<u>Avg. Total % BOD Red.</u>
City Domestic Sewage	1½	4½	91
All Sources "Press Effluent" Out	1½	4½	78
All Sources "Press Effluent" In	1½	4½	63
City Domestic Sewage	3	3	97
All Sources "Press Effluent" Out	3	3	91
All Sources "Press Effluent" In	3	3	92
Mixed Liquor Suspended Solids	Contact Tank 2000 mg/l Stabilization Tank 8000 mg/l		

If a high percentage of BOD is rapidly removed by biological absorption after contact with well aerated activated sludge, the contact stabilization process can be employed to appreciably reduce the aeration tank volume. When the BOD removal rate or percentage reduction is too low to attain the desired over all removal in a short contact period, the contact period can be extended to obtain the desired removal. A substantial increase in the contact period will permit oxidation of the absorbed organics and eliminate the need for stabilization. As the contact period is increased, the contact stabilization then becomes the conventional activated sludge process.

As indicated in Table 4, the contact stabilization based on a relatively short conventional contact time of 1½ hours did not achieve satisfactory BOD removals when the municipal waste was combined with the industrial waste, although contact stabilization achieved 91% BOD reduction with the domestic sewage alone.

Extending the contact time to obtain the desired degree of BOD removals and a performance comparable to conventional activated sludge required a contact period of 3 hours when treating the combined waste flow.

By extending the contact period to 3 hours, the volume required for aeration is not appreciably reduced; thus, the contact stabilization process treating combined waste provides no significant economic advantage over activated sludge. For the combined waste flow with either "press effluent" included or excluded, a contact time of 3 hours and stabilization time of 3 hours was necessary to produce BOD removal comparable to activated sludge.

#### SECTION 4 - SUMMARY AND CONCLUSIONS

Subsequent to the feasibility study for combined municipal and industrial waste treatment submitted to the City in December 1965, a pilot plant investigation to develop basic data for a treatment process for the combined municipal and industrial waste flow from the City of Plattsburgh has been completed. The principal objective of the study was to develop a process to produce an effluent in accordance with a New York State determination, requiring 85% BOD and suspended solids removal.

Biological treatment in the form of activated sludge and contact stabilization was evaluated during these studies.

The pilot plant studies have demonstrated that the conventional activated sludge process should form the basis for the design of the proposed treatment facilities for the City of Plattsburgh. Basic design parameters have been developed and can be applied to the full-scale facilities.

During the course of the study, the contact stabilization modification of the activated sludge process was evaluated because of the possibility of cost savings by reducing the aeration tank volume required for treatment.

Satisfactory BOD removals were not achieved with this modification and it was necessary to expand the contact time until the contact stabilization process approached the aeration volume required for activated sludge.

Data collected on the waste characteristics indicated that primary treatment by sedimentation was necessary due to the large amount of suspended material and grease in the combined waste flow. The studies evaluated the performance of primary settling in terms of suspended solids and BOD removal.

The pilot plant studies produced data upon which the amount of solids to be disposed of can be predicted. Because of the limited site available for the treatment facilities, the difficulties of digesting sludge with large amounts of wood fiber, and because of the high cost of sludge incineration, thickening raw solids, dewatering and land filling for disposal of sludge is under consideration. Large land areas are available, sufficiently remote from the City, where raw dewatered sludge could be economically and feasibly disposed.

Based upon the results of this study for joint treatment of municipal and industrial wastes, the following conclusions can be made:

1. The conventional activated sludge process with primary settling is the basic process necessary to produce the required degree of treatment. No significant economic advantage can be obtained by utilizing the contact stabilization modification of the activated sludge process.
2. Primary settling tanks are necessary before biological treatment. The anticipated BOD removal is 26% and anticipated suspended solids removal 55%.
3. The biological treatment process should be based upon the following parameters:

total detention time	6 hours
Raw flow and recycle	33%
sludge recycle	2500 mg/l +
mixed liquor suspended solids	less than 0.7
# raw BOD applied/# mlss	0.6 (# BOD
Oxygen requirements #/day	removed)
	+ 0.1 mlss
Secondary sludge production #	0.87 (# BOD
	removed)
	- 0.025 (# mlss)

4. Final settling chlorination facilities should be based on conventional design standards.
5. Solids handling and disposal will probably be accomplished by conditioning and dewatering raw sludge for landfill disposal, but this problem is still under consideration.

Figure 1

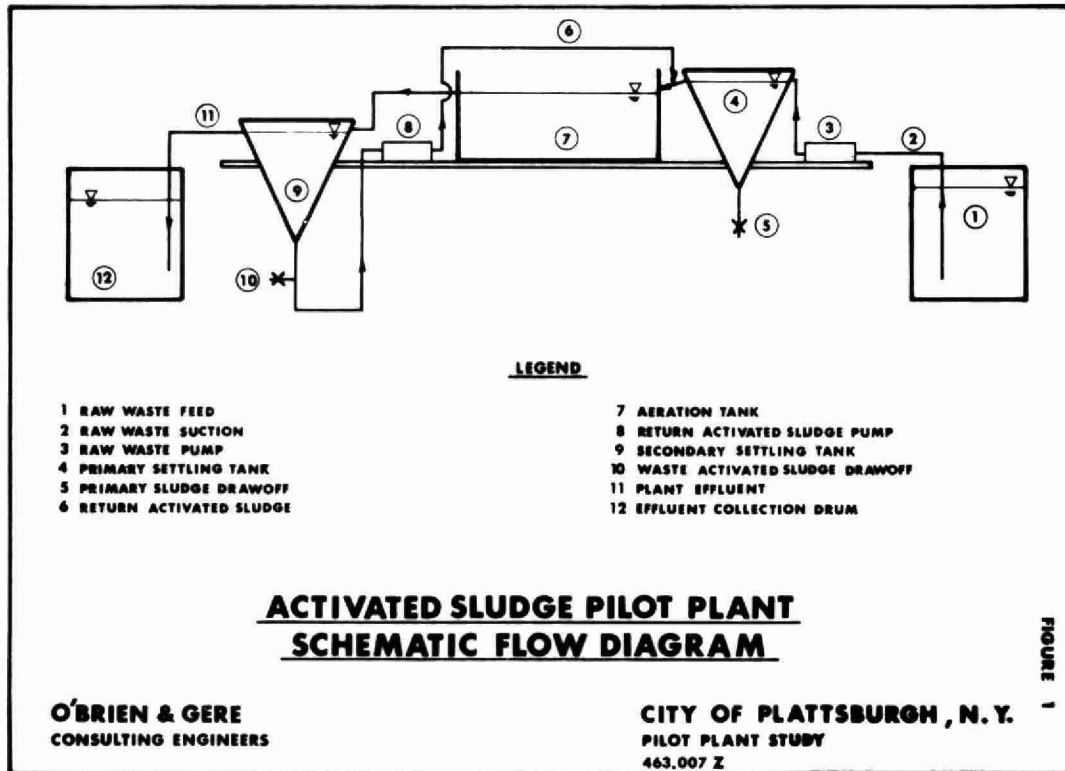


Figure 2

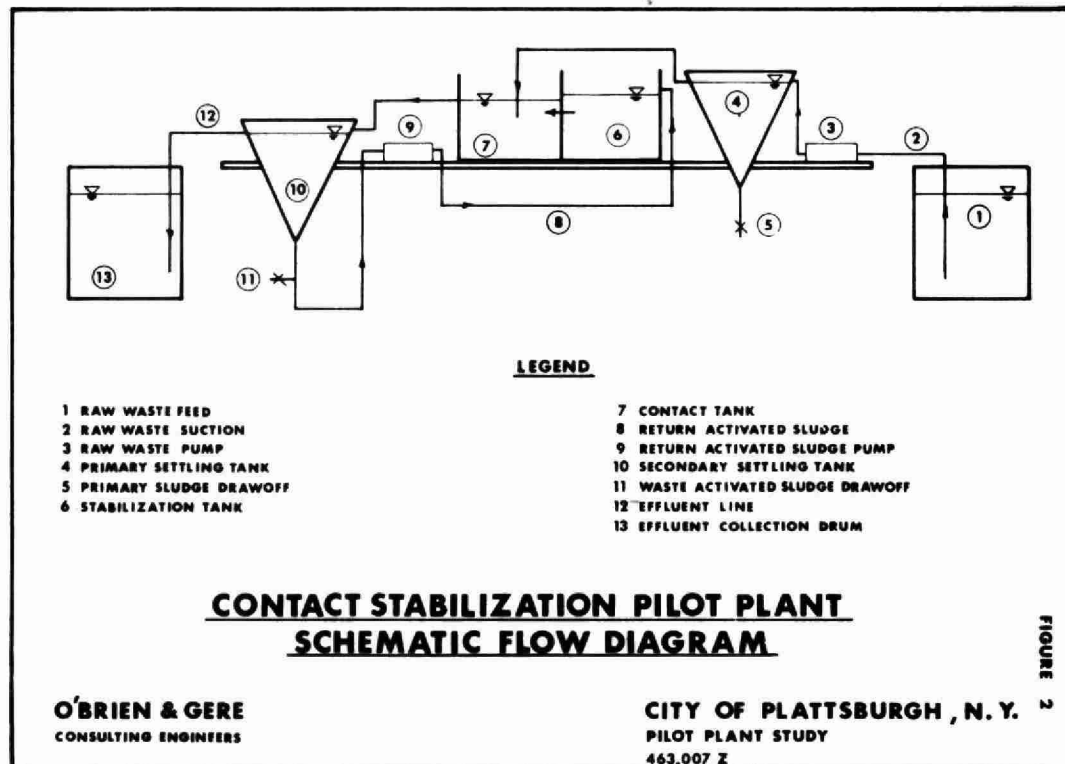


Figure 3

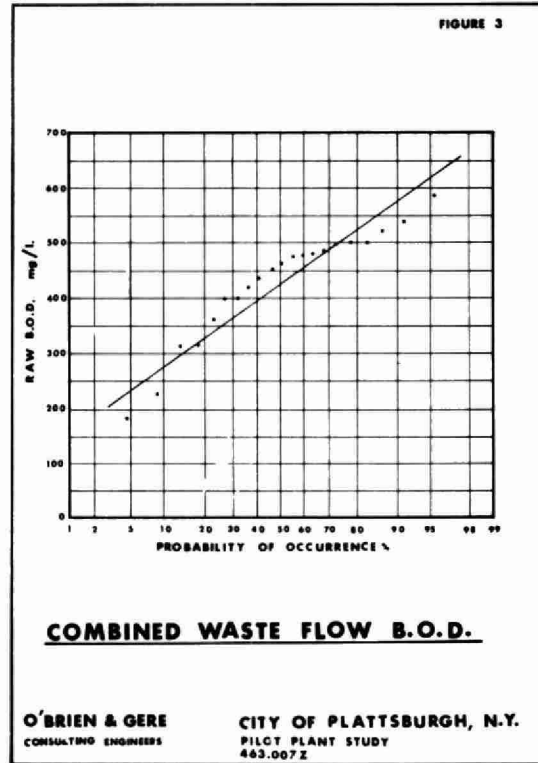


Figure 4

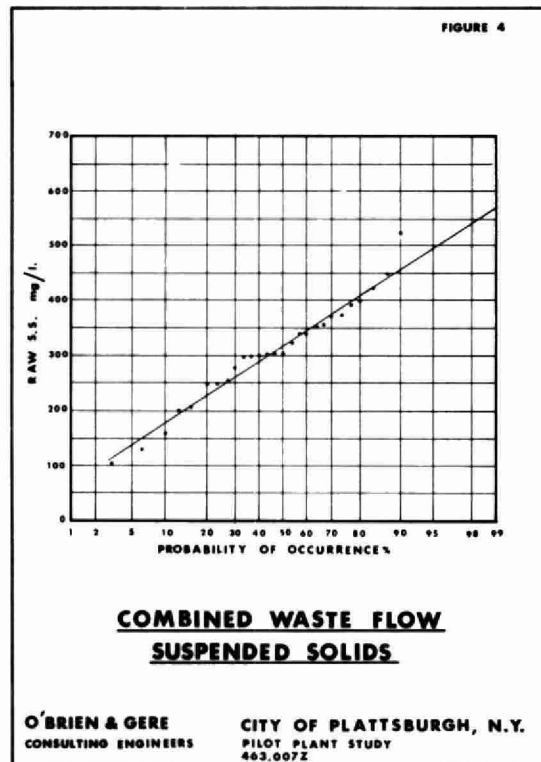


Figure 5

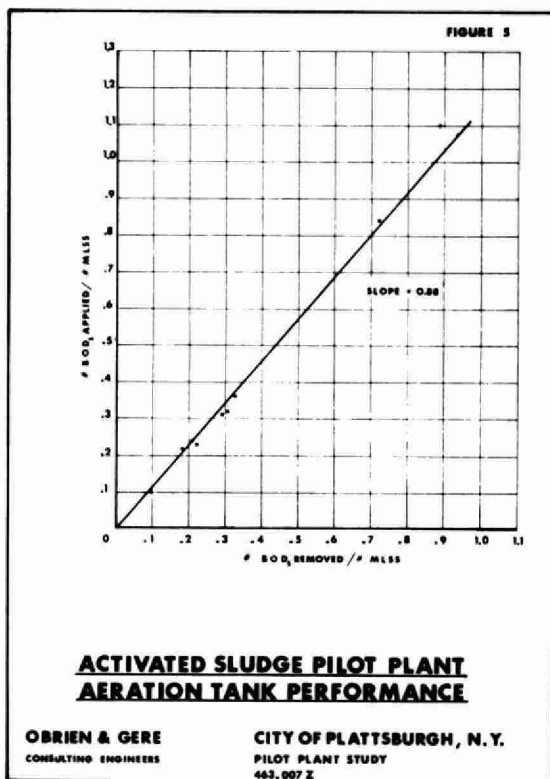


Figure 6

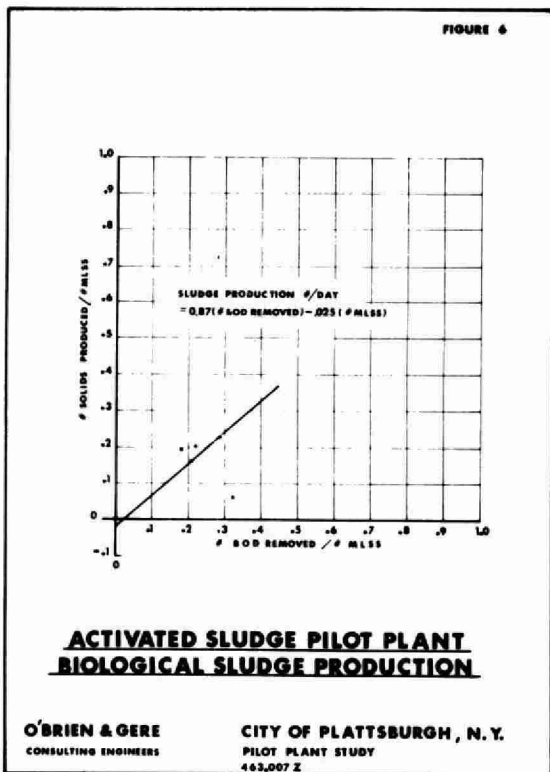




Figure 7

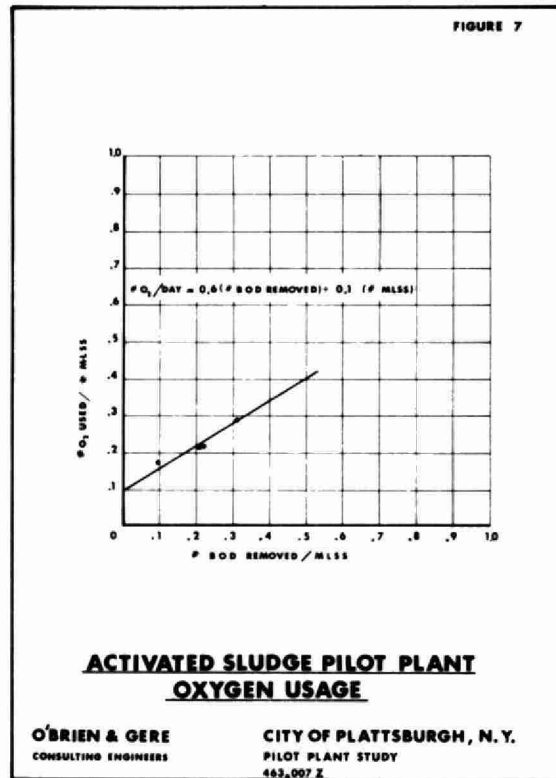
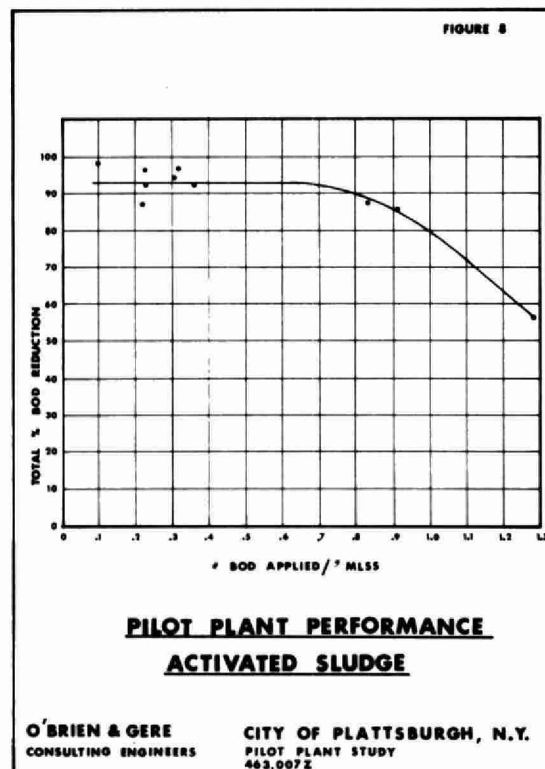


Figure 8





## "ACTIVATED SLUDGE SYSTEM VARIATIONS, SPECIFIC APPLICATIONS"

BY

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### INTRODUCTION

Although previous workers had aerated wastewater flows for odor control or to provide some treatment, Arden and Lockett are generally credited with discovery of the phenomenon that led to the development of the activated system (1). It was found that if the sludge produced from aerated wastewater was collected and added to a new batch of wastewater, and this procedure was repeated a number of times, treatment of the wastewater would occur in progressively shorter aeration periods as more and more of the sludge accumulated. Finally, instead of requiring several weeks of plain aeration to provide the desired level of wastewater treatment, it was found that a high degree of treatment could be achieved by several hours of aeration in the presence of sufficient activated sludge (2).

### SYSTEM CONFIGURATION

The basic design of the activated sludge wastewater treatment system is shown in Figure 1. The chief

structural units include the aeration tank and settling tank. The system influent, that is, the untreated wastewater containing organic matter that is amenable to biological degradation, enters the aeration tank where the organic materials are attacked and stabilized by flora and fauna known collectively as activated sludge. The activated sludge combined with the influent wastewater is known collectively as mixed liquor and the sludge solids contained in the system are termed mixed liquor suspended solids (MLSS).

Mixed liquor is displaced from the aeration tank to the settling unit or clarifier where the activated sludge settles to the bottom and is returned to the aeration tank. The clarified overflow from the settling unit leaves the treatment works as system effluent. Since there is always a net production of biological cell material or sludge by this treatment system, some sludge must be removed from the system, either intentionally as excess sludge or unintentionally in the system effluent (3).

#### SYSTEM DESIGN PARAMETERS

There are many factors in process design and operation that influence the treatment efficiency of an activated sludge system. Some of the general but important process parameters include:

1. Air supply and oxygen transfer efficiency.
2. Weight of active biological mass in the system.
3. Degree of mixing of the active biomass to produce contact with the wastewater flow in an aerobic environment.
4. Biomass loading factor or "food to organism ratio," which is often approximated as pounds of BOD loading per day per pound of mixed liquor volatile suspended solids (lb BOD applied/day/lb MLVSS).
5. Volumetric loading (lb BOD applied/day/1000 cu ft aeration tank liquid capacity).
6. Mixed liquor suspended solids concentration (MLSS).
7. Settling tank configuration, detention time, surface overflow rate, and weir overflow rate.

It will be noted that aeration time has not been included in the above list, since, as has been shown elsewhere, the organic waste uptake rate is related to the weight of activated sludge present, that is, the product of the MLVSS or MLSS concentration and the detention time (4).

There are additional factors, related to the characteristics of the untreated wastewater, that affect system selection and design. To understand how the waste characteristics and desired degree of treatment can determine system design requirements, it is necessary to understand system reaction kinetics.

## SYSTEM REACTION KINETICS

### Physical and Biochemical Reactions

Although there is a continuous fluctuation in the types of organisms found in activated sludge MLSS, it is convenient to visualize the sludge solids as composed of relatively few constituents having certain catalytic properties. The total weight of MLSS ( $M_t$ ) contained in the system will be made up of an active biomass portion ( $M_a$ ), an inactive endogenously produced biomass fraction ( $M_e$ ), and an unassimilated portion ( $M_i$ ) that is due to influent suspended solids that are either adsorbed or remain unattached.

$$M_t = M_a + M_e + M_i \dots\dots\dots(1)$$

On coming in contact with the incoming raw wastewater, the MLSS readily adsorb or enmesh the waste's suspended solids. Colloidal matter is adsorbed quite rapidly by the sludge and soluble constituents are gradually assimilated. Thus, in short term aeration systems, carrying a small weight of organisms, a fairly high fraction of the total sludge mass ( $M_t$ ) may be made up of either free or incorporated but unassimilated influent suspended solids ( $M_i$ ). On the other hand, in extended aeration treatment plants, containing a large weight of biomass, suspended as well as soluble organic wastewater constituents may be largely assimilated and incorporated into the cellular material ( $M_a + M_e$ ). In this case, the weight of unassimilated influent suspended solids would be relatively small but the amount of inactive endogenously produced cell material would be relatively large.

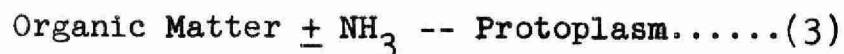
As indicated, sludge may be formed by physical adsorption or by assimilation of waste materials. Metabolism comprises the processes of anabolism and catabolism. Anabolism includes the assimilative reactions, while catabolism results in the breakdown of protoplasm into

elemental constituents including carbon dioxide, ammonia, and water. These metabolic reactions are shown graphically on Figure 2 and can be described by the following stoichiometric equations:

Energy Production:



Protoplasm Synthesis:



Endogenous Respiration:



Endogenous respiration is the internal process in organisms that results in the auto-digestion or self destruction of cellular material. Endogenous respiration utilizes oxygen as does assimilative respiration. Also, since assimilation is always associated with assimilative respiration, it is believed the endogenous synthesis or re-synthesis may accompany endogenous respiration. Apparently, for each 5 units of active biomass that are oxidized and decomposed in accordance with Equation 4, one unit of inert endogenous biomass is produced (5).

Sludge produced by the system, but not oxidized in the system, is removed intentionally from the system as excess sludge or leaves the system in the settling tank effluent. Although short term and conventional activated sludge plants are usually operated with intentional excess sludge removal, extended aeration plants are often operated without intentional sludge removal. In this case, all of the sludge produced will leave the plant in the system effluent. A temporary but significant deterioration of effluent quality may be noted from time to time in a mature, fully loaded extended aeration plant that is operated in this manner. However, as will be noted from Figure 2, the amount of sludge produced by an extended aeration system may be considerably less than that produced in either short term or conventional activated sludge systems.

Soluble Waste Constituents

In a steady state system receiving a wastewater that contains only soluble waste matter, it is possible to formulate a mathematical model that will closely describe

the reaction kinetics of the system:

$$S_t = aF_a - bM_a \dots\dots\dots(5)$$

$$S_a = aF_a - bM_a - eM_a \dots\dots\dots(6)$$

$$O_2 = a'F_a + b'M_a \dots\dots\dots(7)$$

In which  $S_t$  = Total weight of biomass leaving the system  
per unit time, lb SS/day

$S_a$  = Weight of active portion of biomass leaving the  
system per unit time, lb SS/day

$F_a$  = Weight of organic matter assimilated per unit  
time, lb BOD/day

$M_a$  = Weight of active biomass contained in the  
system, lb SS

$O_2$  = Weight of oxygen utilized by the system per  
unit time, lb  $O_2$ /day

$a$  = Weight of active biomass formed per unit  
weight of organic matter assimilated, lb SS/lb BOD

$b$  = Weight of active biomass decrease per unit  
time per unit weight of active biomass in the  
system, lb SS/day/lb SS

$e$  = Weight of endogenous biomass increase per unit  
time per unit weight of active biomass in the  
system, lb SS/day/lb SS

$a'$  = Weight of oxygen utilized per unit weight of  
organic matter assimilated, lb  $O_2$ /lb BOD

$b'$  = Weight of oxygen utilized per unit time per  
unit weight of active biomass in the system,  
lb  $O_2$ /day/lb SS

and  $S_e = eM_a \dots\dots\dots(8)$

where  $S_e$  = Weight of inactive endogenous portion of biomass  
leaving the system per unit time, lb SS/day

Assuming that the effluent suspended solids have  
the same composition as the biomass contained in the system:

$$S_a/(S_a + S_e) = S_a/(S_a + eM_a) \dots\dots\dots(9)$$

$$S_a/(S_a + eM_a) = M_a/(M_a + M_e) \dots\dots\dots(10)$$

Figure 3 has been developed to show system operational parameters for a plant receiving a wastewater containing only soluble waste constituents. It has been assumed that 2 percent of the system influent BOD remains unassimilated and thus passes from the system in the clarifier effluent. The oxygen equivalent of protoplasm has been taken as 1.42 lb  $O_2$  per lb of SS. The following reaction constants were employed:  $a = 0.7$ ,  $b = 0.18$ ,  $e = 0.2(0.18) = 0.036$ ,  $a' = 0.5$ , and  $b' = 1.42(0.18) = 0.256$ . At the indicated sludge wasting rate, an active biomass of about 2 lb SS is required for the assimilation of 1.0 lb  $BOD_5$ /day.

The effluent  $BOD_5$  can be calculated by adding to the unused  $BOD_5$  value the oxygen equivalent of the fraction of active effluent suspended solids that would be endogenously oxidized during a 5-day BOD test. The fractional disposition of a unit weight of active protoplasm that is subjected to endogenous reduction is shown on Figure 4, and the 5-day fractional decrease in active cellular matter was selected from this figure for use in the BOD calculation.

#### Soluble plus Particulate Waste Constituents

The reaction kinetics of systems that receive wastewaters containing both soluble and particulate constituents can also be described by a mathematical model:

$$S_x = aF_a - bM_a + cS_i - dM_t \dots\dots\dots(11)$$

$$O_2 = a'F_a + b'M_a \dots\dots\dots(12)$$

In which  $S_x$  = Weight of excess sludge that is intentionally removed from the system per unit time, lb SS/day

$S_i$  = Weight of influent suspended solids delivered to the system per unit time, lb SS/day

$c$  = Fraction of influent suspended solids not assimilated

$d$  = Weight of sludge that leaves the system in the system effluent per unit time per unit weight of sludge contained in the system, lb SS/day/lb SS

The disposition of influent constituents, for a system receiving a wastewater that contains both soluble and particulate matter is shown on Figure 5.

Due to the fact that it is more convenient to determine the amount of BOD removed by a system rather than the amount of BOD actually assimilated, and since the volatile portion of the MLSS (MLVSS) is commonly used to represent  $M_a$ , Equations 12 and 13 are not actually used at the present time. Also, a rational

method of evaluating  $c$ , the fraction of influent suspended solids not assimilated, has not yet been developed. It is suspected, however, that for short term activated sludge systems,  $c$  has a value close to unity (6). For extended aeration systems, the value of  $c$  may become relatively small. Thus, the value of  $c$  will depend on the fraction of the influent suspended solids that are potentially degradable and on the weight of active biomass contained in the system.

In view of the foregoing difficulties, MLVSS may be used as a crude approximation of  $M_a$  (although this may be considerably in error for extended aeration systems) and the weight of BOD removed (or applied) per day substituted for  $F_a$ . An approximate value can be assigned to  $c$  for any given system loading velocity ( $\text{lb BOD}_5 \text{ removed/day/lb MLVSS}$ ) based on a



the oxygen demand of the waste is gradually removed and the demand for oxygen becomes less and less. Because of this phenomenon, most of the conventional plants built in the past 30 years have been designed to employ tapered aeration as shown in Figure 9. This configuration places the air supply where the demand is greatest (1, 8).

### Step Aeration

As shown in Figure 10, the step aeration system distributes the organic load along the length of the aeration tank, thus evening out the oxygen demand. This system might be more correctly named step loading. The step aeration method of loading results in relatively high mixed liquor solids concentrations at the head end of the tank and progressively lower concentrations downstream. Thus, a step aeration plant can carry a higher weight of organisms in the system than a conventional plant and still maintain a lower suspended solids load on the clarifier.

As a portion of the feed is introduced well downstream in the aeration tank, nitrification of this portion may not be significant. Although this could result in some saving in air requirements, the reduction is quite nominal. Multiple aeration tanks in series are often used in the step aeration system. In this case, the initial aeration chamber can be reserved to re-aerate and rejuvenate the activated sludge return flow, with distribution of the waste flow to the remaining downstream chambers.

Step aeration plants can be successfully employed in the treatment of domestic sewage and wastewater flows of a similar nature. Since the step aeration system is able to hold a relatively higher weight of mixed liquor solids than the conventional system without overloading the settling unit, it has been possible in some cases to convert a conventional plant to a step aeration system. Thus a desirable sludge loading factor has been maintained under increasing plant flows.

### Contact Stabilization

The contact stabilization type of activated sludge plant is shown in Figure 11. Contact stabilization is yet another system that permits use of the same loading factor as that employed with conventional activated sludge but, at the same time, allows up to twice the volumetric loading of the conventional system. In contact stabilization, the volumetric loading may be as high as about 70 lb BOD<sub>5</sub>/day/1000 cu ft of aeration tank capacity.

As indicated diagrammatically, the organisms in the re-aeration unit become lean and hungry in the absence of a food supply and exist in a highly activated form. When finally discharged to the aeration unit that receives the raw wastes,

a relatively small weight of organisms has the capability of removing large amounts of BOD.

The contact stabilization system is ideally suited to the treatment of wastewaters in which a large portion of the BOD is present in suspended or colloidal form (9). The suspended BOD will be rapidly adsorbed in the relatively small aeration tank by the well-activated organisms. When the mixed liquor is displaced to the settling unit, the sludge, which is composed of organisms and adsorbed BOD, is settled out and pumped to the reaeration unit where the adsorbed food is oxidized and thus stabilized. It is reported that the contact stabilization system is not as easily upset by toxic industrial wastes as a conventional activated sludge plant. However, the sludge produced does not compact as readily, and special thickening units may be needed following the final settling tank (10).

As with step aeration, it may be possible to redesign an overloaded conventional activated sludge plant to operate as a contact stabilization system. The redesign may only involve changes in plant piping or channels, and relatively minor modification of the aeration system. The settling tank capacity, of course, would have to be increased if the wastewater flow were increased significantly.

#### Hatfield-Kraus System

The Hatfield variant of the activated sludge system is shown in Figure 12. This process differs from the contact stabilization system in that the anaerobic digester supernatant or, alternatively, digested sludge is fed to the reaeration tank. In the Kraus modification, only a relatively small portion of the return sludge is pumped to the reaeration tank where it is joined by the digester liquor or sludge, and the major portion of the return sludge flow is delivered to the aeration tank in the usual manner (11).

When the waste flow contains large amounts of carbonaceous materials, such as are present in some industrial wastes, the supplying of anaerobic digester effluent to the reaeration unit fortifies the active sludge solids with amino acids and other nitrogenous substances. This is particularly useful for the treatment of industrial wastewaters from fruit and vegetable canneries.

It is held that sudden shock loads, especially of carbonaceous wastes, are one of the main causes of sludge bulking which may be accompanied by voluminous growths of thread-like organisms. The Hatfield-Kraus system can be useful in the treatment of carbonaceous industrial wastes as it has been shown that the maintenance of a proper BOD : Nitrogen : Phosphorus (BOD:N:P) ratio can aid in the prevention of sludge bulking (12).

As with the contact stabilization system, the Hatfield system has the advantage of being able to maintain a large weight of organisms under aeration in a relatively small aeration system.

### Activated Aeration

The activated aeration system shown in Figure 13 is a system, or more correctly a combination of systems, that is able to provide a degree of treatment varying from that associated with the conventional activated sludge system to that associated with short term aeration. It will be noted that the plant depicted in the upper portion of Figure 13 is of the conventional type. The plant shown in the lower portion of the figure is operated in the same manner as the conventional system but, in addition, receives the excess sludge from the associated conventional plant.

The general layout of activated aeration provides a great deal of flexibility in operation, and use of this system should prove economical when employed in situations where the degree of treatment may be adjusted up or down to meet the requirements of the receiving stream.

### Short Term Aeration

Short term aeration systems have extremely high loading factors, varying from about 0.5 up to 5 lb BOD/day/lb VSS based on the total weight of VSS held in the aeration plus tank plus the settling unit. The volumetric loading for the so-called modified aeration variant is about 100 lb/day/1000 cu ft of aeration tank capacity. Supra-activation has a loading factor in the order of 400 lb BOD/day/1000 cu ft of aeration tank capacity.

The short term aeration system offers economy of construction due to very small aeration tank capacities and reduced air requirements. However, since small aeration systems contain relatively low organism weights, the effluent quality will suffer accordingly because of the greater amount of unused BOD remaining in the system effluent. Also, short term systems may be operated at loading factors that are sometimes related to poor sludge settleability and sludge bulking. When loading factors greater than about 0.5 lb BOD/day/lb SS are employed, some reduction in efficiency may be noted at low operating temperatures (13). As will be noted from a review of Figure 2 and the biokinetics equations presented herein, relatively large volumes of sludge are produced per unit weight of BOD removed.

Short term aeration is applicable when a high treatment efficiency is not required. It has been found that a high uptake and retention of phosphorus will occur at high loading factors (lb BOD/day/lb VSS). As a result, it has been proposed

that these systems be used either alone, or in conjunction with a lime-sludge recirculation system around the primary clarifier, for the removal of phosphorus when it is desired to reduce the algae growth potential in the effluent receiving water.

Under high loadings, the sludge entering the final clarifier still contains considerable undegraded organic matter. If an anaerobic environment exists in the clarifier, sludge may float to the surface due to gasification. This has been observed in the treatment of pharmaceutical and cannery wastes at loading factors in excess of 1.2 lb BOD/day/lb MLVSS. Thus, clarifiers that provide rapid sludge withdrawal are indicated when wastes of this nature are treated in short term aeration systems.

However, it is important to note that sometimes an anaerobic environment in the final clarifier is a good thing. In the case of a waste containing a source of readily available carbon, strains of filamentous organisms can dominate and result in a difficult to settle or bulking sludge. The maintenance of anaerobic conditions in a final clarifier having a long sludge detention time will usually eliminate the filamentous forms. The foregoing phenomenon has been noted in the treatment of a pulp and paper waste by means of a short term aeration system (6).

#### Extended Aeration

The extended aeration type of activated sludge system is represented by two configurations shown in Figure 15. Extended aeration plants are characterized by relatively small loading factors and high system sludge weights. Loading factors range from about 0.05 to 0.2 lb BOD/day/lb VSS. The volumetric loading for domestic wastewater is generally about 10 to 20 lb BOD/day/1000 cu ft of aeration tank capacity.

As usually operated on the North American continent, the extended aeration process has no intentional wasting of sludge from the system. This means that the net growth of VSS is wasted from the system in the process effluent. Because of this phenomenon, normal domestic sanitary flows typically have an apparent BOD removal in the order of 75 to 85 percent when treated by this process. In some European installations, however, the excess sludge is intentionally removed from the system and in this case, the process can be operated at BOD removal efficiencies approaching that of conventional activated sludge.

It is important to note several characteristics about the effluent quality of the extended aeration process when sludge is not intentionally removed from the system. Because of the large organism weight contained in the system, the unused BOD fraction is relatively small. Also, because of the large organism weight, there is a correspondingly large decrease of new or



initial growth of volatile sludge by endogenous respiration such that a relatively small amount of net growth of volatile sludge results. In addition, the volatile sludge is less reactive and has a lower BOD than an equivalent weight of sludge produced by processes having larger loading factors. It is for these reasons, even if the net growth of sludge does leave the system in the process effluent, that the effluent is of fairly good quality. These relationships can be clarified further by a review of Figures 2 and 6, and the relevant biokinetics equations.

Extended aeration systems have a wide variety of applications. In communities of less than roughly 5000 persons, the use of an extended aeration system is usually preferred when the quality of effluent required, as dictated by receiving water conditions, is equivalent to that of a primary treatment plant. In such cases, the extended aeration plant would be operated without intentional sludge removal. If required, the treatment could be upgraded by simply providing period sludge withdrawal from the system.

Other advantages of the extended aeration system include the fact that the process efficiency is not affected by low operating temperatures; the system can withstand relatively large changes in influent flow rate and waste concentration; and the system can absorb relatively large shock loads of toxic substance.

Because the extended aeration system tends to produce small quantities of sludge, it is useful in the treatment of high-carbohydrate industrial wastes, which in a conventional activated sludge plant would have a high conversion to biological sludge. Milk wastes have been treated with notable success in extended aeration plants.

### Aerated Lagoons

Aerated lagoons are essentially large basins, usually of 10- to 15-foot depth, that are provided with either mechanical or diffused aeration. The aerated lagoon is usually designed to provide relatively long detention periods, the degree of treatment being related to the detention time provided and the concentration of organisms held in suspension. Often, detention periods of 10 to 20 days are used in the treatment of domestic wastewater flows, although when a low degree of treatment is required, there appears to be no reason why shorter detention times cannot be employed. In any event, the aeration equipment selected must be able to provide the intensity of aeration necessary for adequate mixing and oxygen transfer.

Aerated lagoons are widely employed in the treatment of pulp and paper mill wastes and are applicable to wastes that vary greatly in character and which would upset other activated

sludge variants. The aerated lagoon system is capable of operating under intermittent organic loading and at lower nutritional requirements as measured by the BOD:N:P ratio, and is thus applicable in the treatment of cannery wastewater flows. Because of the great capability of diluting incoming wastes, this system can be employed for the stabilization of predominantly organic wastes that may contain an occasional slug of toxic chemicals.

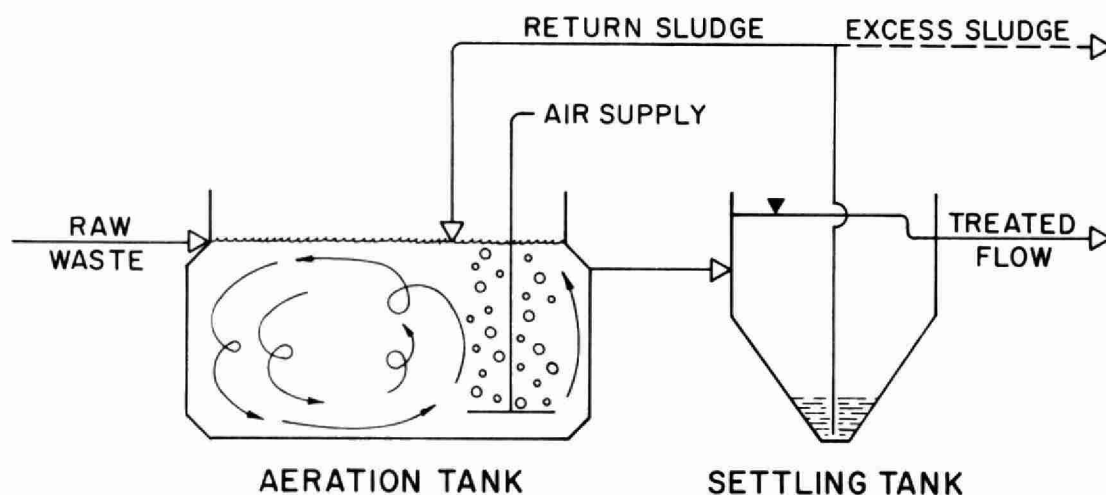
#### Water Cooling Tower

A novel application of the activated sludge treatment system is that shown on Figure 16 for the treatment of refinery or petrochemical wastewaters by means of a cooling tower (14). The following is quoted from the treatise entitled Biological Treatment of Petroleum Refinery Wastes, American Petroleum Institute, New York:

It is a mechanical activated sludge system in which oxygen is transferred from the air into the mixed liquor, through the cooling tower, and the excess activated sludge is continuously discharged into the effluent. Some biological growths are retained on the wooden slats within the cooling tower, similar to a trickling filter, but the quantity of adhered growths appears small compared to the suspended growth.

It would appear that the cooling tower acts in a similar manner to an activated sludge aeration tank in that it provides a means of holding and aerating the mixed liquor. Waste sludge is removed from the system by blowdown and occasional wind losses. The water cooling tower system has proven effective in BOD and phenol reduction.

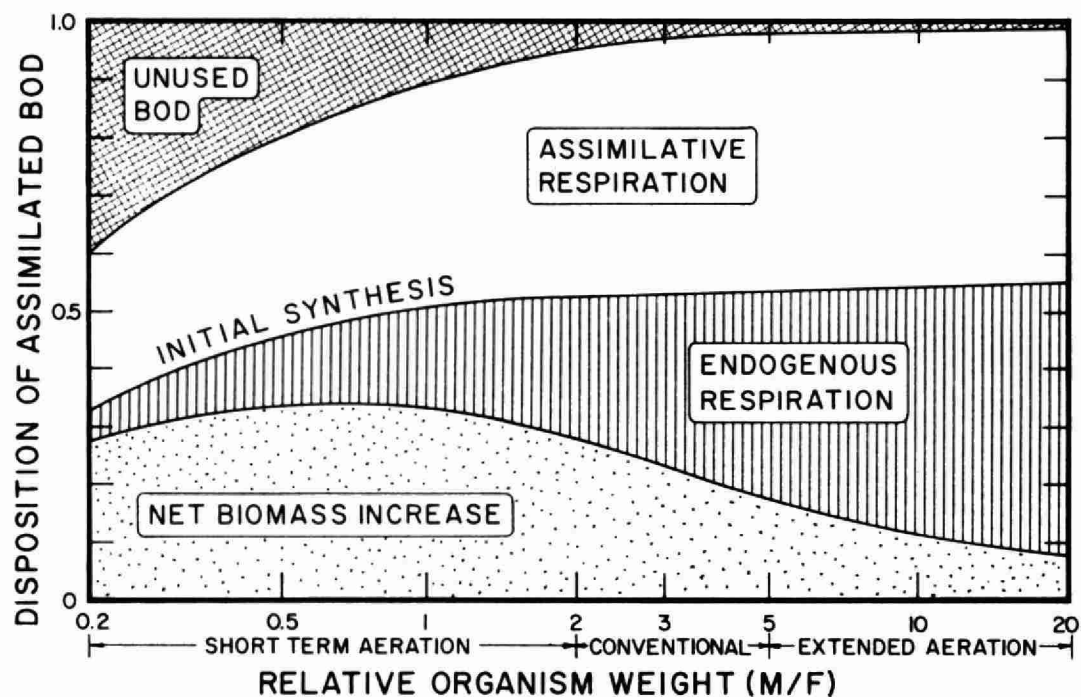
Figure 1



# ELEMENTS OF THE ACTIVATED SLUDGE SYSTEM

FIGURE 1

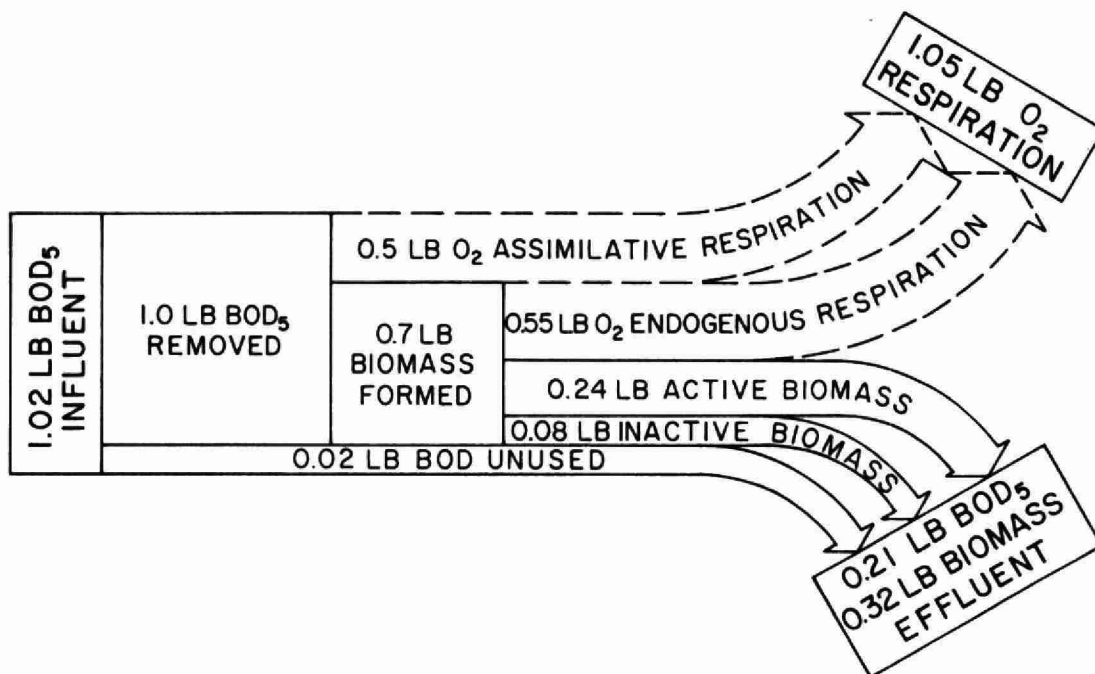
Figure 2



# METABOLIC REACTIONS FOR THE COMPLETE SPECTRUM

FIGURE 2

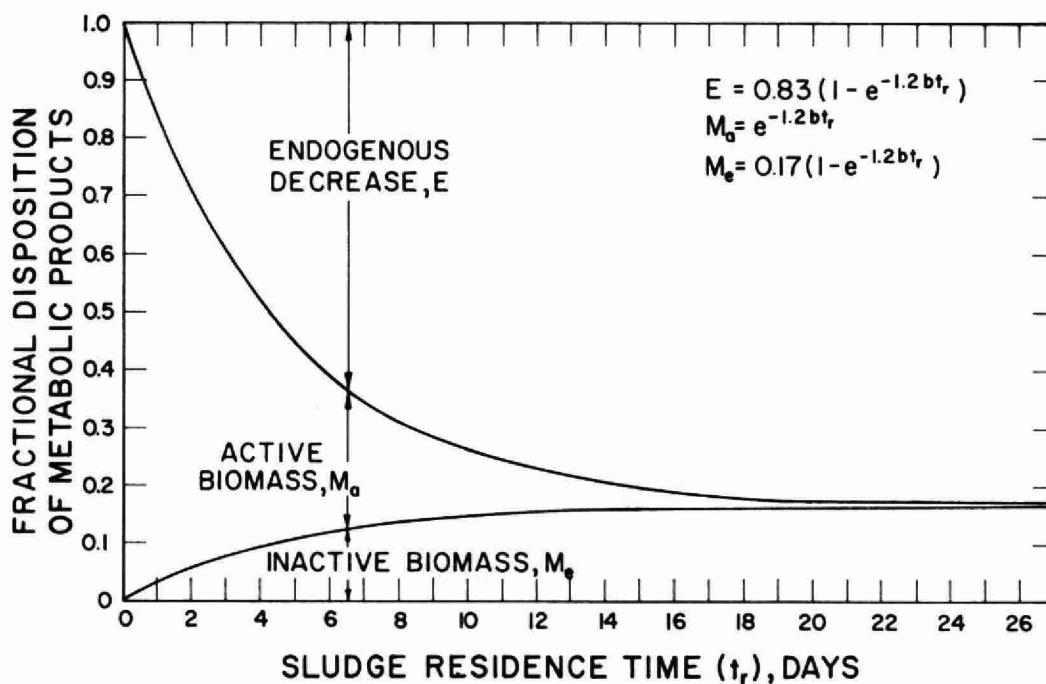
Figure 3



# SYSTEM METABOLISM FOR SOLUBLE WASTES

FIGURE 3

Figure 4

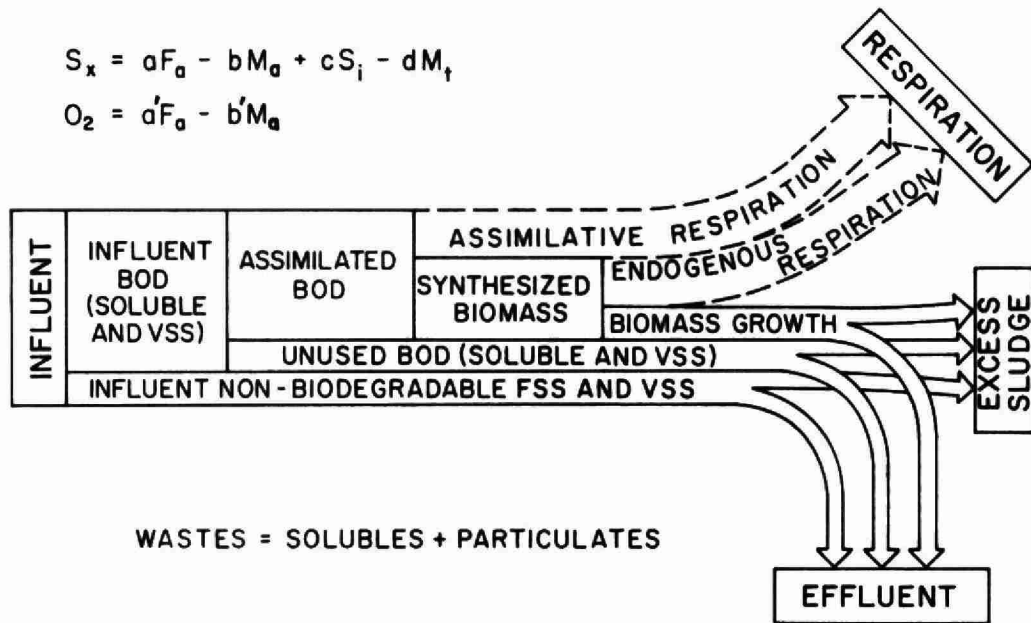


# BIOMASS COMPOSITION AND RESIDENCE TIME

FIGURE 4



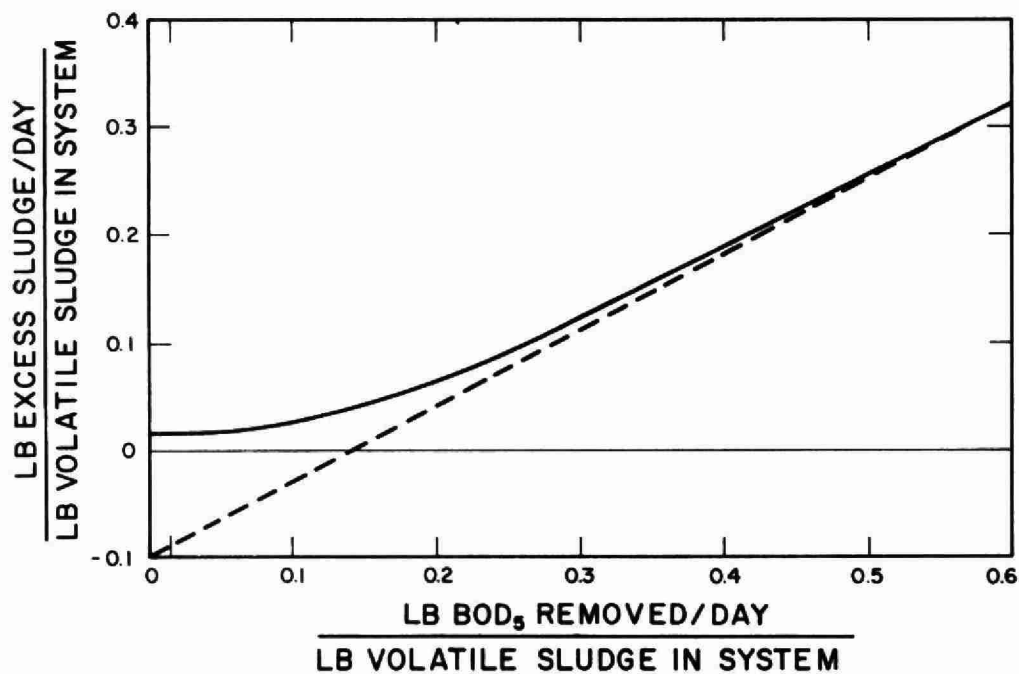
Figure 5



METABOLISM AND PROCESS REACTIONS

FIGURE 5

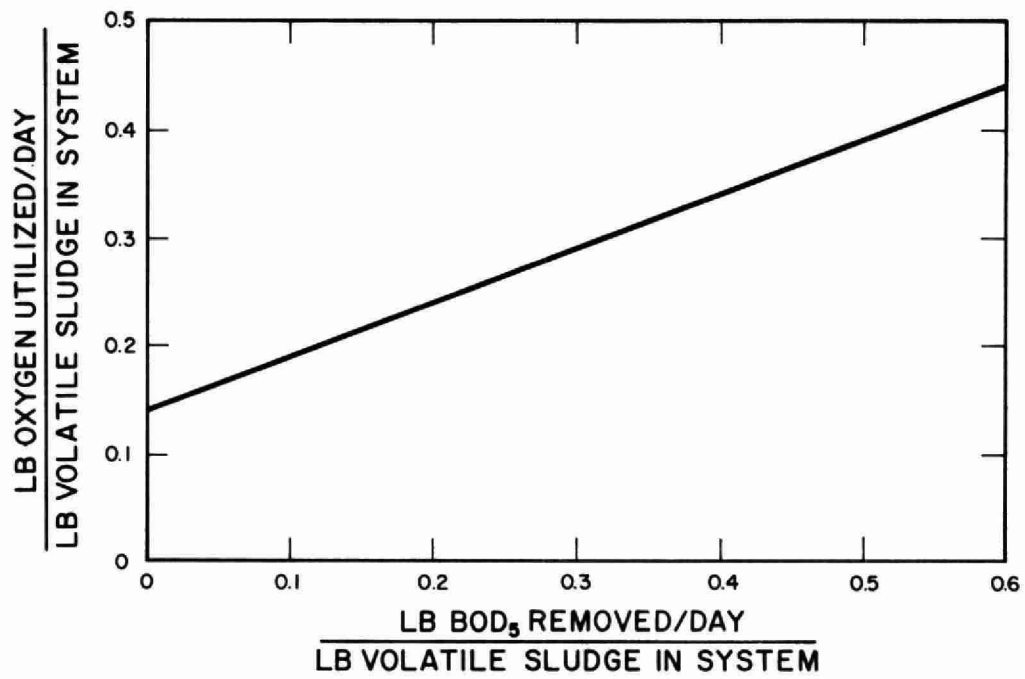
Figure 6



EXCESS SLUDGE PRODUCTION

FIGURE 6

Figure 7



## OXYGEN REQUIREMENTS

FIGURE 7

Figure 8

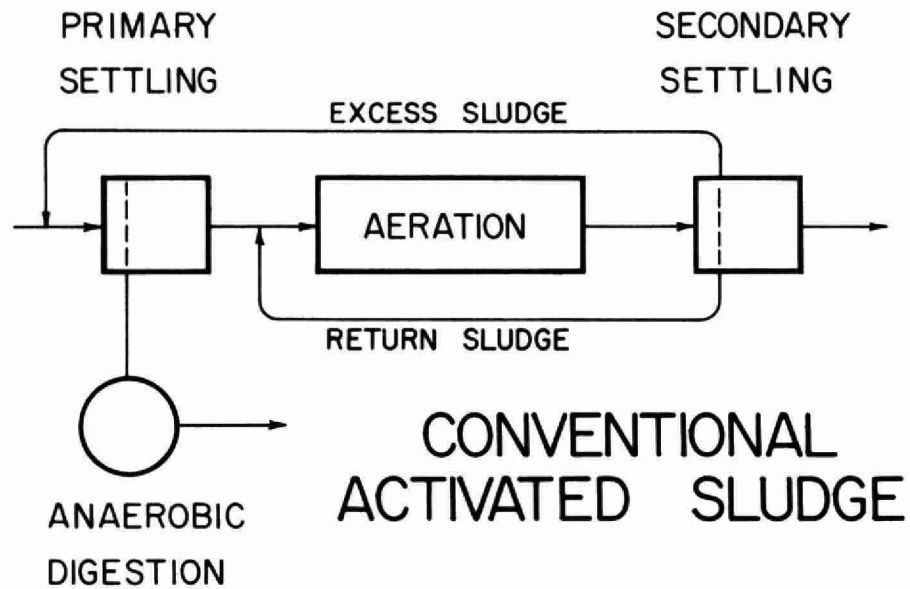
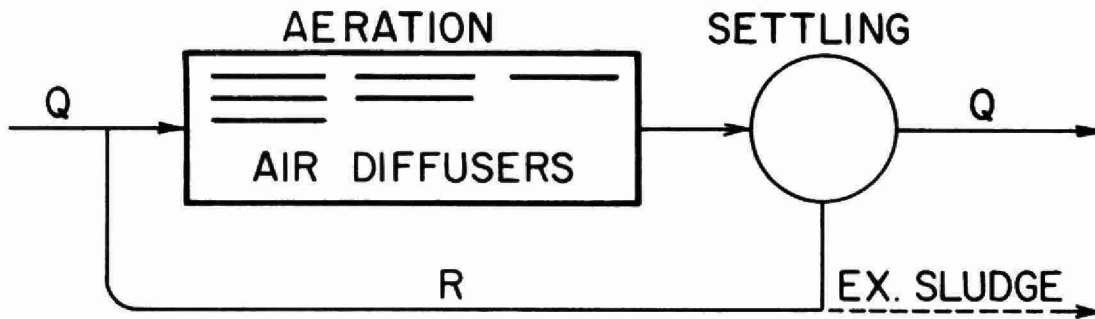


FIGURE 8

Figure 9

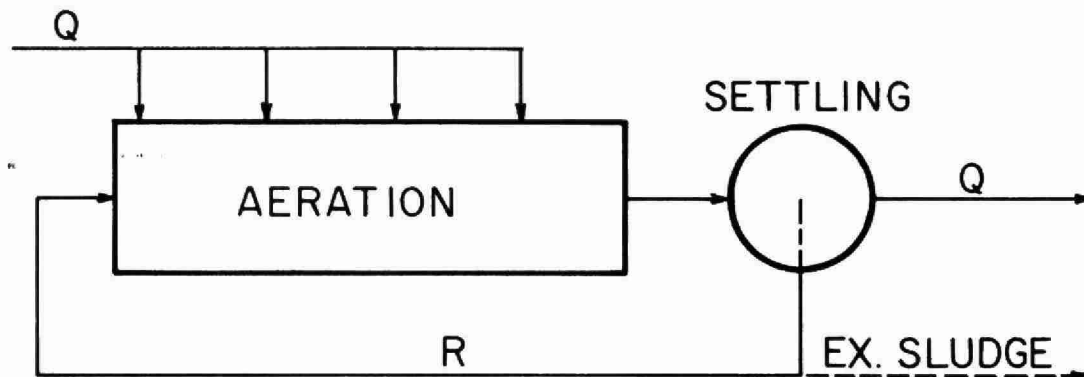


35 LB BOD/DAY/1000 CU. FT.

## TAPERED AERATION

FIGURE 9

Figure 10



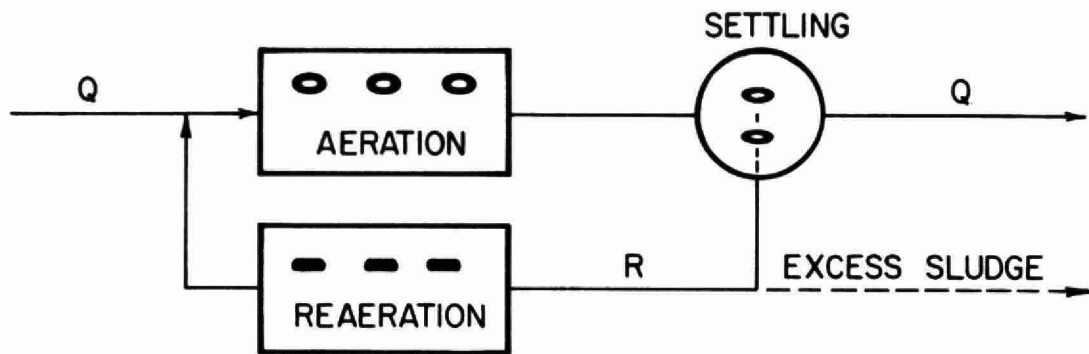
50+ LB BOD/DAY/1000 CU. FT.

## STEP AERATION

( STEP LOADING )

FIGURE 10

Figure 11

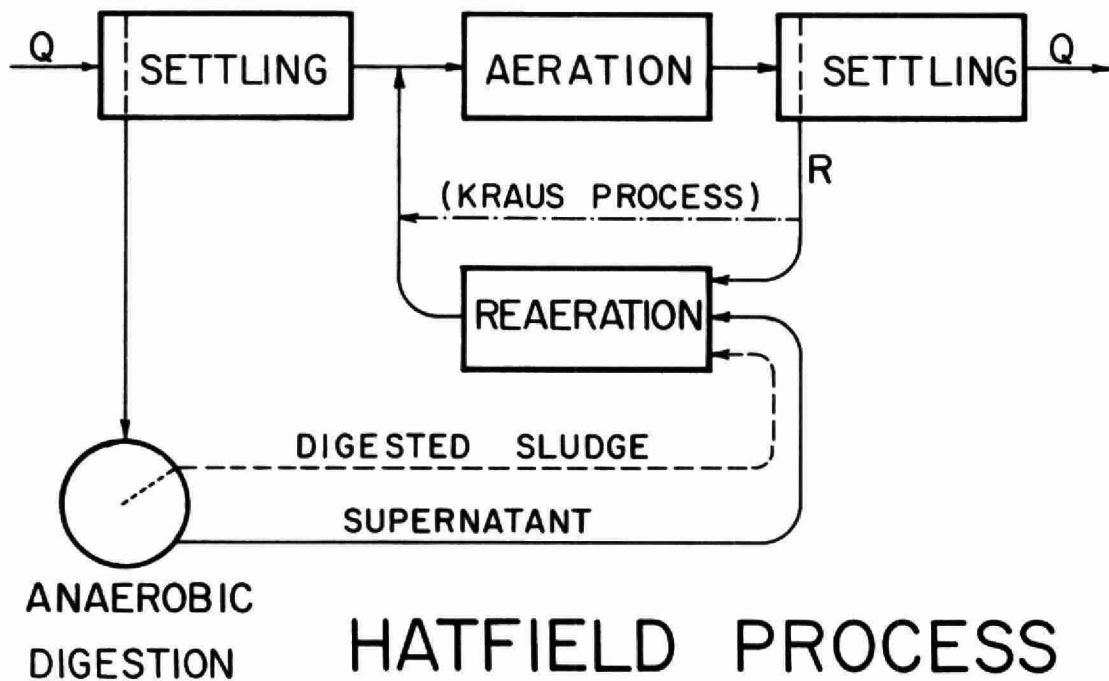


70 LB BOD/DAY/1000 CU. FT.

## CONTACT STABILIZATION

FIGURE 11

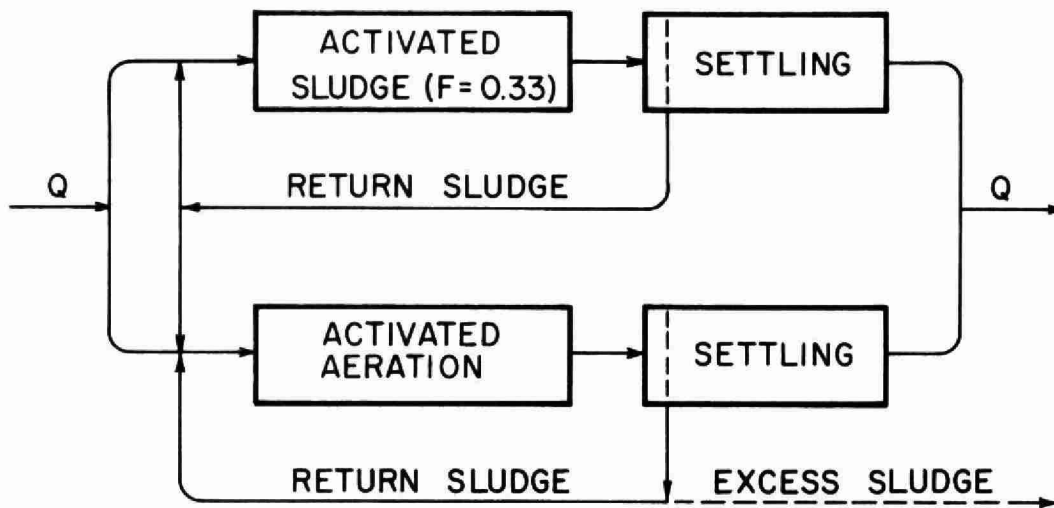
Figure 12



## HATFIELD PROCESS

FIGURE 12

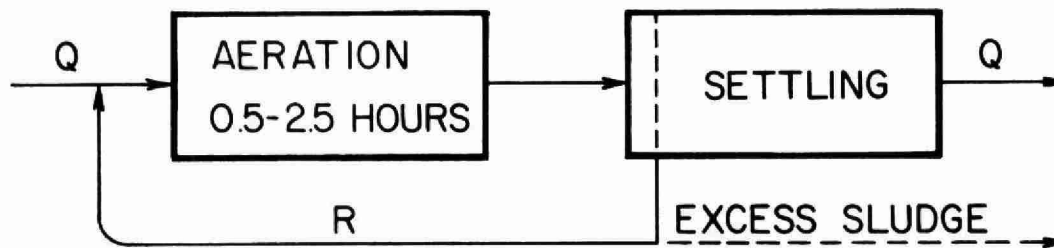
Figure 13



## ACTIVATED AERATION

FIGURE 13

Figure 14

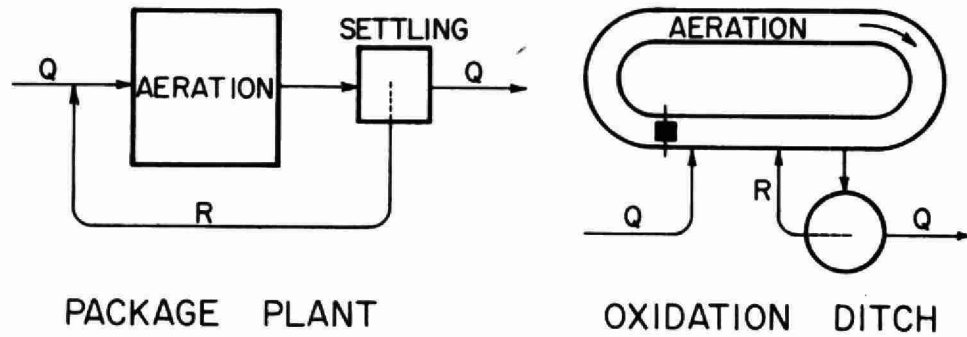


	<u>LB BOD/DAY</u> <u>1000 CU. FT.</u>	<u>LB BOD/DAY</u> <u>LB V. SLUDGE</u>
SUPRA ACTIVATION	400	3.5 - 5
MODIFIED AERATION	100	2 - 5
HIGH RATE AERATION	100	2 - 5
RAPID BLOC	150 +	0.5 - 1

## SHORT TERM AERATION

FIGURE 14

Figure 15



20 LB BOD/DAY/ 1000 CU. FT.

## EXTENDED AERATION

FIGURE 15

Figure 16

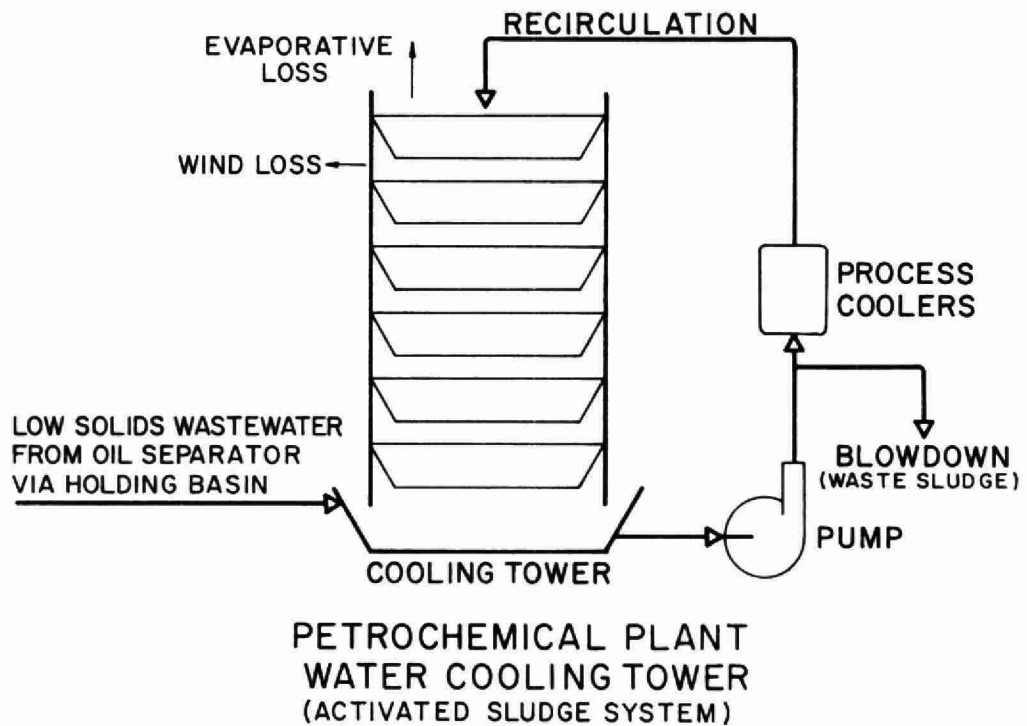


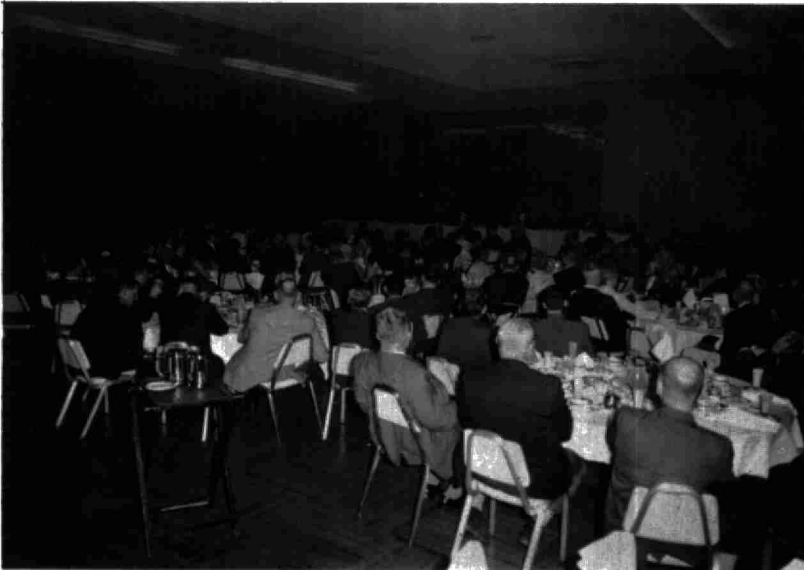
FIGURE 16

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BANQUET NIGHT





**'NEW APPROACHES TO WASTE  
WATER TREATMENT'**

**BY**

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**ABSTRACT**

This paper reports on some aspects of the research and development work being carried out on waste treatment technology by the Cincinnati Water Research Laboratory of the Federal Water Pollution Control Administration (FWPCA). Pilot plant activities as well as large-scale treatment plants supported partially by FWPCA Research and Development Grants to cities, sanitary districts and states are included. The individual projects range from single-unit processes to complete treatment systems incorporating biological, chemical and physical treatment techniques. The scale of each project depends on both the stage of technological development of the treatment processes involved and the flow requirements considered necessary for evaluating a specific treatment objective. Project flows range from two hundred to several million gallons per day (gpd). Project objectives include:

- (1) technical and economic evaluation of a process

or a complete treatment system, or (2) development of methods for reducing water pollution of a given type or at a specific location. An example of the latter would be the production of water suitable for underground recharge to prevent salt water intrusion, or for reuse in industrial, agricultural, recreational or other applications.

Typical of the treatment techniques discussed are two-stage lime precipitation with lime recovery and reuse, granular activated carbon adsorption, and a variety of biological and chemical techniques for removing the algal nutrients, nitrogen and phosphorus.

Among the many pressing environmental problems facing us today, those related to our air and water resources are among the gravest. There is presently widespread interest regarding the treatment and handling of wastewaters because of the effect these waste streams have on our usable water supplies, and also because future needs in some areas will require reclaimed water for direct reuse. In a relatively few years our once limitless supply of clean water has seriously diminished--so much so that the problem has become a matter of nationwide concern. Streams and lakes which once served as clean water sources have been steadily and increasingly used as receptors for untreated or only partially treated domestic and industrial liquid wastes.

Although wastewater treatment is commonly practiced throughout the country, the degree to which pollutants are removed has been

inadequate to prevent countless streams and lakes from receiving excessive amounts of suspended materials, oxygen consuming materials, nutrients, and toxic wastes. Under extreme conditions, these waters become unsuitable for normal domestic uses and in many cases they are rendered unsuitable as habitats for fish and other biological species normally present in natural waters.

Basic aspects of the conventional waste treatment process are shown schematically in Figure 1. Primary treatment includes sedimentation to remove a portion of suspended solids and BOD, and sludge disposal. Secondary treatment includes biological oxidation utilizing either trickling filters or activated sludge units with final sedimentation for separation of the biological floc.

Although highly effective in removing 80 to 95% of the influent BOD and suspended solids, conventional treatment does not normally remove enough of the pollutants to make the water completely suitable for many reuse applications including recreational lakes, underground recharge or for most industrial or domestic uses. Depending on the type of wastewater, the degree of treatment received and the assimilative capacity of the receiving stream or lake, the treated effluent may not even be suitable for discharge to natural waterways.

Urgently needed are improved treatment processes for more effective removal of organics and suspended solids which are only partially removed by conventional treatment, and new treatment techniques capable of removing dissolved pollutants not ordinarily removed at all by conventional treatment.

Several physical-chemical and biological treatment techniques have been investigated for technical and economic feasibility during recent years. The most promising of these are now being further developed in pilot-scale and full-scale plants. New approaches to wastewater treatment are not limited to new processes and are not necessarily intended to replace conventional treatment processes. In reflecting both the cost of treatment and the specificity of the process used, treatment by new approaches will generally be tailored to the individual waste

involved and to the quality of effluent required.

It is the purpose of this paper to describe several new treatment systems now under development including modified conventional processes. In most cases the processes described are still experimental even though they are being proposed for full-scale or pilot-scale development. Evaluations are being conducted at plants treating municipal wastes in order to guarantee realistic results under actual operating conditions.

#### POLLUTANTS OF INTEREST

In designing a tailored treatment facility for a specific waste stream, it is necessary to know the pollutants of concern and the processes capable of effecting their removal. Table 1 lists the pollutants normally present in municipal wastewaters, and includes the treatment processes currently used or being developed for their removal.

#### PILOT-PLANT AND FULL-SCALE PLANT STUDIES

Tertiary processes are being or will be evaluated at many locations including those listed in Table 2. Several of these plants are currently in the design and construction stages. Experimental plants at Lake Tahoe and Pomona, California and at Lebanon, Ohio, have been in operation for several years. Process flows being studied range up to 7.5 million gallons per day (mgd).

Chemical coagulations, sedimentation, filtration, and granular carbon adsorption are being studied at seven plants. Considerable emphasis has been placed on these processes to reduce nutrients and organics because they represent major contributions to the over-all water pollution problem.

Past studies have also included processes for removal of dissolved organics, and work in this area is now being accelerated.

TABLE 1

WASTEWATER POLLUTANTS AND APPLICABLE TREATMENT PROCESSES

1. SUSPENDED SOLIDS

- a. Sedimentation
- b. Screening
- c. Coagulation-sedimentation by addition of polymer, lime or alum
- d. Filtration

2. BIODEGRADABLE ORGANICS

- a. Biological treatment
  - Trickling filter
  - Activated sludge
- b. Removal of particulate BOD by same processes as shown for suspended solids
- c. Activated carbon adsorption

3. NONBIODEGRADABLE ORGANICS AND COLOR

- a. Activated carbon adsorption
- b. Chemical oxidation

4. DISSOLVED INORGANIC MATERIALS

- a. Electrodialysis
- b. Reverse osmosis
- c. Chemical precipitation
- d. Ion exchange

5. NUTRIENTS

Nitrogen

- a. Biological nitrification-denitrification
- b. Ammonia stripping by air contacting

Phosphorus

- a. Chemical precipitation with inorganic salts
- b. Biological removal

TABLE 2

FULL-SCALE AND PILOT-PLANT STUDIES

TERTIARY PROCESSES

		FLOW (MILLION GALLONS PER DAY)	STATUS*
1.	<u>CHEMICAL COAGULATION, SEDIMENTATION, FILTRATION, AND GRANULAR CARBON ADSORPTION</u>		
	a. S.Lake Tahoe, California	7.5	0
	b. Piscataway, Maryland	5	D
	c. E.Chicago, Indiana	0.75	D
	d. Nassau County, New York	0.55	D
	e. Dallas, Texas	0.15	D
	f. Washington, DC	0.10	0
	g. Lebanon, Ohio	0.07	0
2.	<u>DIRECT CARBON TREATMENT OF SECONDARY EFFLUENT</u>		
	a. Pomona, California - Granular Carbon	0.3	0
	b. Lebanon, Ohio - Powdered Carbon	0.015	0
3.	<u>AMMONIA STRIPPING</u>		
	a. S.Lake Tahoe, California	7.5	0
	b. Piscataway, Maryland	0.2	D
	c. Washington, DC	0.1	D
	d. Manassas, Virginia (Supernatant)		D
4.	<u>ELECTRODIALYSIS</u>		
	a. Lebanon, Ohio	0.07	0
	b. Santee, California	0.025	D
	c. Pomona, California	0.015	D
5.	<u>ION EXCHANGE</u>		
	a. Santee, California	0.025	D
	b. Pomona, California	0.003	0
6.	<u>REVERSE OSMOSIS</u>		
	a. Hemet, California	0.05	D
	b. Pomona, California	0.005	0

\* D - Design or Construction

0 - In Operation

Various modifications of conventional treatment processes are being developed to increase the removal of nutrients and organics (see Table 3). Improved treatment achieved by modifying conventional plants offers the possibility of increased removal of organics and nutrients at lower costs than would be possible by tertiary treatment.

## CURRENT STATUS OF TREATMENT TECHNOLOGY

In designing a system to achieve a given degree of treatment, the over-all cost must be kept to an absolute minimum. It is therefore essential to know the capability of every treatment process under realistic operating conditions. To develop such information, each process must be subjected to pilot plant evaluation and progressively upscaled as applicability and design data are determined. Final answers for optimized systems may be some time in coming; however, enough information and answers are currently available to permit intelligent and prudent design capable of increasing pollutant removal in many areas. The following discussion indicates the present stage of development of various processes and presents alternative treatment techniques available or being developed for achieving different treatment objectives.

### 1. Conventional Biological Treatment

#### a. Experimental Biological Pilot Plant

A 100,000 gallons per day (gpd) dual-train experimental biological pilot plant will be installed at the District of Columbia Water Pollution Control Plant in Washington, D.C. The planned facility is shown schematically in Figure 2. This biological plant will operate in conjunction with the existing FWPCA-DC tertiary pilot plant at the same location. One train of the biological treatment plant will furnish effluent to the tertiary processes under study; the second biological train will serve to study various activated sludge process modifications. The pilot facility is designed for complete flexibility which will permit almost any desired treatment arrangement. Aeration tanks will be equipped with both diffusers and mechanical aerators, and are designed for both completely mixed or plug flow operation.



TABLE 3

FULL-SCALE AND PILOT-PLANT STUDIES

CONVENTIONAL PROCESS MODIFICATIONS

	FLOW (MILLION GALLONS PER DAY)	STATUS*
1. <u>ACTIVATED SLUDGE PROCESS</u> <u>MODIFICATION FOR INCREASED</u> <u>NUTRIENT REMOVAL</u>		
a. Manassas, Virginia	1	D
b. Santee, California	2	D
c. Irvine, California	2	D
d. Chino, California	3	D
2. <u>COMBINED TRICKLING FILTER -</u> <u>ACTIVATED SLUDGE PROCESS</u>		
a. Dallas, Texas	0.75	D
b. Ventura, California	0.075	0
3. <u>DUAL TRAIN EXPERIMENTAL ACTIVATED</u> <u>SLUDGE PLANT</u>		
a. Washington, DC	0.10	D
4. <u>POLYMER ADDITION TO PRIMARY</u> <u>SEDIMENTATION</u>		
a. Washington, DC	240	0
5. <u>MINERAL ADDITION TO ACTIVATED SLUDGE</u> <u>PROCESS FOR PHOSPHORUS REMOVAL</u>		
a. Pomona, California	2	0
b. Santee, California	2	D
c. Irvine, California	2	D

\* D - Design or Construction

0 - In Operation

This combination of an experimental biological and tertiary pilot plant will permit studies to establish the most effective and economical way to operate different treatment systems for any desired effluent quality; studies should delineate factors needing control, and develop design requirements and operating procedures to achieve process optimization.

b. Two-Stage Biological Treatment

Trickling filters are generally less effective than the activated sludge process for removing suspended solids, BOD, and nutrients. Although they adjust better to variations in hydraulic flow, their treatment capabilities are limited. In many applications trickling filters will have to be supplemented by additional treatment to produce a final effluent suitable for meeting current and future water quality requirements.

At Ventura, California a 75,000 gpd experimental pilot facility will attempt to utilize the best of both treatment techniques by evaluating the feasibility and advantages of using the activated sludge and trickling filter treatment in different treatment sequences. The immediate objective for the Ventura installation is to establish economic and technical feasibility as well as reliable design data. The individual steps shown schematically in Figure 3 include; primary clarification, high-rate trickling filter, activated sludge, and final clarification.

Combinations to be studied following primary sedimentation include:

- (1) Activated sludge - sedimentation -  
trickling filter - final sedimentation.
- (2) Activated sludge - Trickling filter -  
final sedimentation.
- (3) Trickling filter - activated sludge -  
final sedimentation.

A potential advantage of the trickling filter-activated sludge treatment sequence is the ability of the high-rate trickling filter to withstand major variations in both hydraulic and pollutant loadings.

As a result, the substrate inoculum to the activated sludge process will be relatively uniform. The activated sludge-trickling filter treatment sequence has the potential advantage that the trickling filter will flocculate the activated sludge effluent, insuring a final product of maximum clarity and minimum solids content.

Although the two-stage biological treatment concept has been used in England and to a limited extent in this country, better data are required to establish the most effective treatment conditions.

## 2. Suspended Solids and Particulate BOD Removal

### a. Screening

Fine mesh screening using a rotary drum configuration has been used successfully (5,10) on secondary effluent to achieve 75 to 85 percent removal of suspended solids and 60 to 80 percent BOD removal at a cost of about \$0.015/1,000 gallons (based on a 10 mgd plant). A disadvantage of screening is susceptibility to wide variations in flow and suspended solids concentrations.

### b. Filtration

Coarse media filtration will provide removal efficiencies (10) comparable to screening but at a higher cost (\$0.025/1,000 gallons). Coarse media filtration has two advantages: (1) the filtration facilities can be salvaged if subsequent needs dictate the use of fine media filtration; (2) partial removal of phosphorus can be achieved by adding coagulants prior to the filter. Complete phosphorus removal is impractical by this technique because of the severe solids load imposed on the filter.

## 3. Phosphate Removal

### a. Chemical Precipitation with Inorganic Salts

#### (1) Digester Supernatant Treatment

Treatment of digester supernatant is a relatively new and promising approach being investigated for nutrient removal. This waste stream

is a concentrated source of both phosphate (50-200 mg/l) and nitrogen (300-1,000 mg/l). If 95 percent of both nitrogen and phosphorus present in the supernatant can be removed, over-all plant efficiencies would approach 40 percent. Since digester supernatant constitutes only 3 to 5 percent of the plant flow, treatment costs expressed as cents per 1,000 gallons of plant flow should be low. Processes under study include lime precipitation and ammonia stripping.

## (2) Mineral Addition to Aerators

Addition of sodium aluminate to the aerator in the activated sludge process has proved effective in removing up to 90 percent of phosphorus. This process which has been piloted at 100 gpd<sup>(3)</sup> and field evaluated at 1 mgd<sup>(4)</sup>, can be employed without constructing additional facilities other than chemical feeders. Approximately one part of aluminum, as sodium aluminate, is required per part of influent phosphorus. Under the conditions studied, the aluminum phosphate and aluminum hydroxide precipitates formed have not affected operation of anaerobic digesters. Weight of sludge is increased but volume is not significantly changed. Costs are estimated at \$0.03/1,000 gallons (10 mgd). Additional studies are being conducted at the Cincinnati Water Research Laboratory and at Irvine, Pomona, and Santee, California.

## (3) Tertiary Clarification

Single-stage tertiary lime or alum clarification is an effective method of achieving effluent phosphate concentrations to 3 mg/l or less as  $PO_4$ . Subsequent filtration can remove an additional 1 to 2 mg/l of phosphate at a cost equivalent to clarification. Choice of coagulant is dependent on wastewater characteristics and effluent quality objectives. Based on limited experience, lime has been more effective on hard waters than on soft, and has cost advantages both in raw materials and sludge disposal. Lime sludges can be thickened, dewatered, recalcined, slaked and reused. The major cost savings associated with recovery and reuse of lime results from the reduced quantity of sludge requiring ultimate disposal. A 100,000 gpd single-stage lime clarification and filtration system has been in operation at the Lebanon Pilot Plant for

over a year. Estimated cost of the lime clarification step is about \$0.035/1,000 gallons (10 mgd). Fine media filtration would add another \$0.035/1,000 gallons.

The concentration of phosphate remaining in lime-treated wastewater is a function of pH and relatively independent of the initial phosphorus concentration. In the case of alum treatment, the stoichiometry requires 2 parts of aluminum per part of phosphorus, and residual phosphorus concentration is a direct function of initial phosphorus content and alum dose. Therefore, alum treatment should be applied to waters with low phosphorus content and lime would be preferable for waters with high phosphorus concentration.

A 0.5 mgd plant employing alum coagulation, filtration and carbon adsorption is in operation in Nassau County, New York to reclaim wastewaters for underground injection to prevent salt water intrusion.

(4) Lime Precipitation of Raw Wastewater-  
Phosphate Extraction Process (PEP<sup>TM</sup>)\*

The PEP\* Process (1) is a system involving chemical and biological methods for phosphate removal with lime recovery and reuse. Unlike most other reclamation approaches which add a tertiary step or modify conventional secondary treatment, this process starts with chemical treatment of the raw wastewater. The treatment sequence, shown in Figure 4, includes: (1) Lime clarification of the raw wastewater, (2) lime recovery and reuse, (3) activated sludge, (4) alum coagulation if necessary, and (5) final sedimentation.

\*Trademark of Dorr-Oliver, Inc., Stamford, Connecticut (Use of trade name does not constitute an endorsement or recommendation by the Federal Government of the item or product mentioned).

Lime dosage to the raw wastewater will be determined by (1) the permissible concentration of phosphate in the final effluent, and (2) the amount of phosphate that can be removed by the activated sludge process. However, the degree of phosphate removal achieved by lime precipitation is limited by the allowable pH in the aerator influent. Where further removal of phosphate is required, alum is added to the final clarifier, as shown in Figure 4. Since the phosphate concentration at this point would be quite low, the increased removal should be relatively economical.

In addition to removing most of the phosphate, 85 percent of the suspended solids and 65 to 75 percent of the raw BOD can be removed by lime clarification. This greatly reduces the BOD load to the aerator and results in a 50 percent reduction in the amount of waste activated sludge.

#### b. Biological Uptake

High-rate nutrient removal is a relatively new approach for removing carbon, phosphorus and nitrogen. This is a novel treatment technique which takes advantage of bacterial utilization of carbon, phosphorus and nitrogen for cell growth, thereby removing these compounds from solution. The basic step is a modified activated sludge process designed to promote high-rate bacterial cell production. Organic loadings of up to 30 lbs BOD/lb of mixed liquor volatile suspended solids (MLVSS) in the aerators (F/M of 30 ) will be evaluated. Conventional activated sludge employs a food to mass (F/M) ratio of about 0.3. At the high F/M ratios maintained in this approach, the biological population will be in the log growth phase as opposed to the endogenous respiration stage typical of conventional design. Success of the method depends on high rates of bacterial cell growth to utilize phosphorus and nitrogen and rapid separation of the solids from the liquid.

In this process the 6-hour detention time commonly used in conventional activated sludge may be reduced by as much as 50 percent thereby effecting appreciable cost savings in plant construction and operation.

At Chino, California this concept will be evaluated in a 3 mgd plant designed to produce water suitable for recreational and irrigation uses. The treatment sequence, shown schematically in Figure 5, consists of: (1) primary settling, (2) modified activated sludge, and (3) solids separation. The primary settler and modified activated sludge unit have a design flow of 3 mgd. Sedimentation will be used initially for solids-liquid separation, with parallel studies on rapid separation processes being conducted at a scale of 0.3 mgd. When the rapid solids separation process has been optimized, it will be enlarged to handle the entire plant flow of 3 mgd.

Two processes for rapid solids-liquid separation will be evaluated: (1) microscreening (SWECO vibrating screen), and (2) dissolved air flotation. If needed, chemical addition can be made prior to the separation unit. Rapid removal of bacterial cells from the water under aerobic conditions is essential to prevent leaching of the phosphorus back into solution and to concentrate the cells for return to the aerator.

A comparison of critical operating and loading factors for the modified activated sludge (MAS) under study and conventional activated sludge (CAS) processes is given below:

	Organic Loading lbs BOD/lb MLVSS*	Detention Time, Hrs	Return Sludge, %	MLVSS* mg/l	Phosphorus Removal, %
MAS	10-30	0.5	10	400	50-75
(Study Range)	(0.3-20)	(0.5-3)		(220-3,000)	
CAS	0.3	4-6	25-50	2500	15-25

\*(MLVSS) - Mixed Liquor Volatile Suspended Solids



### c. Ion Exchange

Synthetic anion exchange resins are available for phosphate removal. Selectivity of the resin for phosphate ions is a critical factor because other anions are competing for exchange sites. Due to their higher valence, the phosphate ions are preferentially removed ahead of chloride, nitrite, or nitrate. Unfortunately, the resin has about the same selectivity for sulfate ions as for phosphate ( $\text{HPO}_4^-$ ), thus the exchange capacity of the resin must be shared between these two similarly charged anions. Since wastewaters generally contain 2 to 5 times more sulfate than phosphate ions, the exchange capacity for phosphate ions is significantly reduced. Until synthetic exchange resins can be made highly selective for phosphate, they will not be economically practical for phosphate removal.

## 4. Nitrogen Removal

### a. Ammonia Stripping

Nitrogen normally occurs in secondary effluents as either ammonium ion or nitrate ion. Up to 95 percent of the ammonia can be air-stripped from solution using about 400 ft<sup>3</sup> of air per gallon of water treated. Effective ammonia removal requires a pH of 11. The cost of air stripping is estimated at about \$0.015/1,000 gallon (10 mgd).<sup>(8)</sup> A nitrified secondary effluent cannot be treated by this method.

Ammonia stripping has been piloted at South Lake Tahoe and a full-scale stripping tower has been constructed to handle the 7.5 mgd flow. This step will be part of the two-stage lime precipitation process. A schematic diagram of the Tahoe treatment system is shown in Figure 6. Lime is added in the first stage to raise the pH to 11. This step removes most of the suspended solids, phosphates, and carbonate compounds. Effluent from the first-stage clarifier is then subjected to countercurrent air contacting to remove ammonia; effluent from the cooling tower is recarbonated with  $\text{CO}_2$  to precipitate excess calcium as  $\text{CaCO}_3$  in the second-stage clarifier; at this point the pH is dropped to 9.5. Addition of small dosages of alum, poly-electrolyte or activated silica ahead of the filters may be necessary to



maintain product clarity in the second-stage effluent.

b. Two-Stage Biological Nitrification and Denitrification

Nitrogen can also be removed from wastewaters by the progressive biological oxidation of nitrogen compounds to nitrites and nitrates followed by conversion to nitrogen gas. This two-stage process, termed nitrification-denitrification, involves aerobic and anaerobic biological stages, respectively. Nitrification is typically achieved in an activated sludge aeration tank by extending the normal aeration time and by employing lower ratios of BOD to mixed liquor suspended solids than in conventional design. Denitrification results from anaerobic bacteria utilizing oxygen from the nitrates. Since the nitrified effluent is deficient in carbon, this stage of treatment requires the addition of an organic supplement such as methanol. The denitrification step may be achieved in a separate tank with mechanical mixing or by developing a population of denitrifying organisms within carbon columns or sand filters following the aerators.

c. Three-Stage Biological Nitrification and Denitrification

A new approach to biological nitrification is a three-stage separate sludge system developed at the Cincinnati Water Research Laboratory of FWPCA. (2) A schematic arrangement of this process is shown in Figure 7.

The first stage is a high-rate activated sludge process where 80 percent of the carbonaceous material in the primary effluent is converted to bacterial cells and carbon dioxide in approximately two hours. Effluent from this stage contains residual carbon and most of the influent nitrogen in the form of ammonia. The second stage is the nitrification step having its own sludge system consisting of an enriched culture of nitrifiers. Nitrification is accomplished in three hours. The third stage is the denitrification step. Since most of the carbon has been utilized in the previous stages, methyl alcohol is added to provide the proper C-N ratio. By accurately controlling the dosage, methyl alcohol is

completely oxidized so that no residual remains in the final effluent. During laboratory studies the process has been capable of removing 85 percent of the nitrogen. This new treatment technique will be further developed in a 0.2 mgd pilot plant at Manassas, Virginia.

5.           Refractory Organic Removal

a.   Carbon Adsorption

(1)   Granular Carbon Adsorption

Carbon adsorption is used primarily for the removal of non-biodegradable organics, color and residual BOD. Suspended solids are also removed in most applications and the solids load and need for pretreatment must be considered when designing a carbon adsorption system. The used carbon must be regenerated and reused for carbon treatment to be economical. Large-scale plants currently using and regenerating granular activated carbon include Lake Tahoe (7.5 mgd), and Nassau County, New York (0.5 mgd).

At the Pomona, California Pilot Plant<sup>(7)</sup>, secondary effluent is applied directly to the carbon columns without requiring excessive backwashing. This is possible because of exceptionally high quality secondary effluent at this location.

Treatment costs range from \$0.035 to \$0.08/1,000 gallon (10 mgd) depending on the degree of treatment desired. Current design for a high degree of treatment involves pressurized flow through 3 or 4 columns in series at a flow rate of 6-7 gpm/ft<sup>2</sup> to provide a contact time of 35 to 40 minutes. This produces an effluent containing only 1 to 3 mg/l of total organic carbon (TOC)\*. When a column is exhausted, the carbon is dewatered and regenerated in a multiple-hearth furnace at about 1650°F in a steam-air atmosphere.

\*(TOC) - Total Organic Carbon Concentration

## (2) Powdered Carbon Adsorption

The use of powdered activated carbon for the treatment of wastewater is accomplished by slurry contacting. This treatment approach has been developed in a 10 gpm pilot plant at Lebanon, Ohio. The process is carried out in a two-stage countercurrent flow system. After adequate contact time, the powdered carbon is settled out along with other suspended solids in the water. Filtration of the settled effluent can produce high quality water with low organic content. The estimated cost of treatment is approximately \$0.11/1,000 gallons (10 mgd). Methods of regenerating powdered activated carbon for reuse are being developed. Fluidized bed heating appears to have promise as a regeneration technique.

### b. Chemical Oxidation

Chemical oxidation offers an alternate method to carbon adsorption for removing refractory organics. Several oxidation techniques are being evaluated in laboratory studies. These include: (1) ozone treatment, (2) ultraviolet light-catalyzed chlorine oxidation, (3) catalytic oxidation in the presence of oxygen or air, and (4) use of liquid oxygen. Chemical oxidation for organic removal is considered to be technically feasible but at present is not considered economically competitive with carbon adsorption.

## 6. Dissolved Inorganic Removal

Demineralization will not ordinarily be required for pollution control purposes but will be necessary for reuse applications involving domestic supplies, some industrial uses, and underground injection where dissolved salts in the ground water are already at maximum allowable concentration levels. Three demineralization techniques show considerable promise and are currently being evaluated under pilot plant conditions. There are: (1) electrodialysis, (2) ion exchange, and (3) reverse osmosis.

### a. Electrodialysis

A 42 gpm electrodialysis stack has been under study at the Lebanon, Ohio Pilot Plant for about three years. (6) To prevent clogging or fouling of

the membranes, the wastewater influent must be relatively free of suspended and colloidal particulates as well as organics. At Lebanon, pretreatment has consisted of single-stage lime treatment followed by dual-media filtration and granular carbon adsorption. Approximately 40 percent of the 800 mg/l dissolved salts are removed by this process. The waste stream amounts to less than 10 percent of the feed stream. Ion removal is essentially nonselective. The treatment costs for electrodialysis are estimated at \$0.14/1,000 gallons for a 10 mgd plant.

b. Ion Exchange

Techniques for demineralization of wastewaters by ion exchange are relatively undeveloped at present. Some work has been done on laboratory and pilot scale which indicates that multiple-stage treatment can be employed to achieve complete demineralization. This is in contrast to the 40 percent removal of dissolved salts by single-stage electrodialysis. Estimated treatment costs of \$0.25/1,000 gallons are higher than for electrodialysis, but the process becomes competitive if only half of the stream is completely demineralized and then blended with the remaining effluent to achieve over-all partial demineralization at a cost comparable to electrodialysis.

The foregoing concept will be investigated at Santee, California. This will be one aspect of the complete wastewater treatment project shown schematically in Figure 8. The 25,000 gpd ion exchange process consists of two anion exchangers and one cation exchanger. This is the Kunin weak base-weak acid process which uses 3 columns: the first and third columns are weak base, and the middle column is weak acid. Only 2 of the 3 columns are regenerated since the final column ion exchanger becomes the first column on a reverse flow treatment. Of considerable interest in this study will be parallel operation of an electrodialysis stack to develop comparative data for the two methods of demineralization.

c. Reverse Osmosis

Reverse osmosis has the capability of removing both dissolved organics and inorganics. This process has only recently shown promise as a wastewater

treatment technique and is presently being extensively studied. Several membrane types and configurations have been developed and will be evaluated at various pilot plants and wastewater treatment plants. At Hemet, California five separate configurations, each rated at 10,000 gpd, will be subjected to parallel comparisons (See Figure 9).

An important part of this study will be to determine the extent of pretreatment necessary before the wastewater can be introduced into the reverse osmosis units. Preliminary results obtained at the Pomona, California Pilot Plant indicate severe fouling of membranes by suspended solids; also there is deterioration of cellulose acetate membranes by biological attack. The seriousness of these problems is significantly reduced by proper pretreatment.

Pretreatment processes to be evaluated at Hemet will include:

- (1) Solids removal by alum coagulation, flocculation, sedimentation, and rapid sand filtration.
- (2) Organic removal by granular carbon adsorption in a downflow column with a detention time of 36 minutes.
- (3) Polishing for removal of residual solids by diatomaceous earth filtration. This step will remove biological growths which develop on carbon columns and slough off during normal operation of the system.
- (4) Acid addition for pH adjustment to 5.5. pH control is necessary to prevent hydrolysis of the acetate groups which would degrade the membrane.
- (5) Chlorination to prevent biological attack of the membranes.

Because the process is still undeveloped for waste treatment application, cost estimates range from \$0.25 to over \$1.00/1,000 gallons for a 10 mgd plant.

Improvements in the cost picture for reverse osmosis as a wastewater treatment process would result from such advances as:

- (1) Achieving high flux rates of 20 to 30 gpd/ft<sup>2</sup>.
- (2) Developing longer-lived membranes by preventing deterioration.
- (3) Optimizing the degree of pretreatment required.
- (4) Improving the product-to-waste ratio; currently waste is 10 percent of throughput.
- (5) Reducing membrane costs through development of additional markets.

#### COST OF TREATMENT

The economics of wastewater treatment will be a major factor in selection of a treatment system for a given waste stream and effluent quality. Costs for conventional plants and projected costs for some tertiary processes are shown in Table 4.<sup>(9)</sup> Estimates shown are for a 10 mgd plant and include amortized construction, operating, and maintenance costs.

Judged by present standards, costs for tertiary treatment may seem high. Cost of complete treatment beyond conventional processes for removal of nutrients, organics, and inorganics is estimated at \$0.26 to \$0.30/1,000 gallons as compared to \$0.11/1,000 gallons for secondary treatment. With the higher degree of treatment, the reclaimed water becomes salable for reuse applications; consequently, the advanced treatment costs immediately become less burdensome.

TABLE 4

ESTIMATED UNIT COSTS FOR WASTE  
TREATMENT PROCESSES - 10 MGD SCALE

COST  
(CENTS/1,000 GAL)

CONVENTIONAL PROCESSES

Primary Treatment	6.3
Activated Sludge (includes Primary Treatment)	11

FILTRATION

Microscreening	1.5
Coarse Media	2.5
Fine Media	3.5

PHOSPHATE REMOVAL

Mineral Addition to Aerator	3
Coagulation, Sedimentation	3.5
Coagulation, Sedimentation, Filtration	7

AMMONIA STRIPPING	1.5
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GRANULAR CARBON ADSORPTION	3.5-8
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DISSOLVED INORGANIC REMOVAL

Electrodialysis	14
Reverse Osmosis	25-100
Ion Exchange	25

## LIST OF FIGURES

- Figure 1 - Conventional Primary and Secondary Treatment
- Figure 2 - Experimental Biological Treatment Facility
- Figure 3 - Two-Stage Biological Treatment
- Figure 4 - Phosphate Extraction Process (PEP<sup>TM\*</sup>)
- Figure 5 - High-Rate Nutrient Removal
- Figure 6 - Tertiary Treatment Including Chemical Nutrient Removal
- Figure 7 - Biological Nitrification and Denitrification
- Figure 8 - Complete Conventional and Tertiary Treatment
- Figure 9 - Demineralization by Reverse Osmosis with Pretreatment Units

\*Trademark Dorr-Oliver, Inc., Stamford, Connecticut.

Figure 1

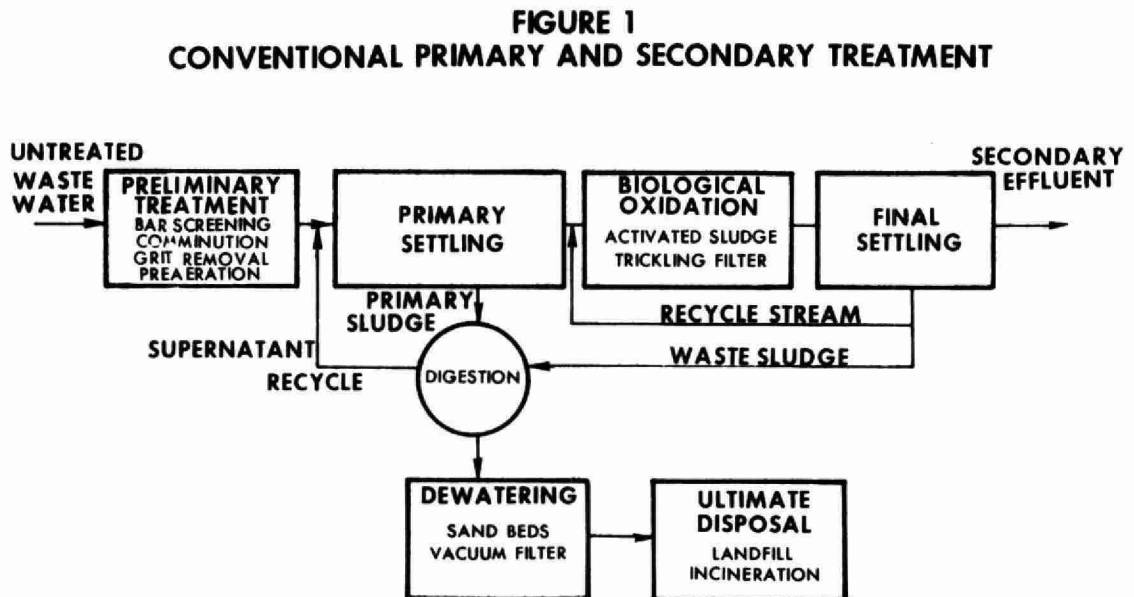




Figure 2

## FIGURE 2 EXPERIMENTAL BIOLOGICAL TREATMENT FACILITY

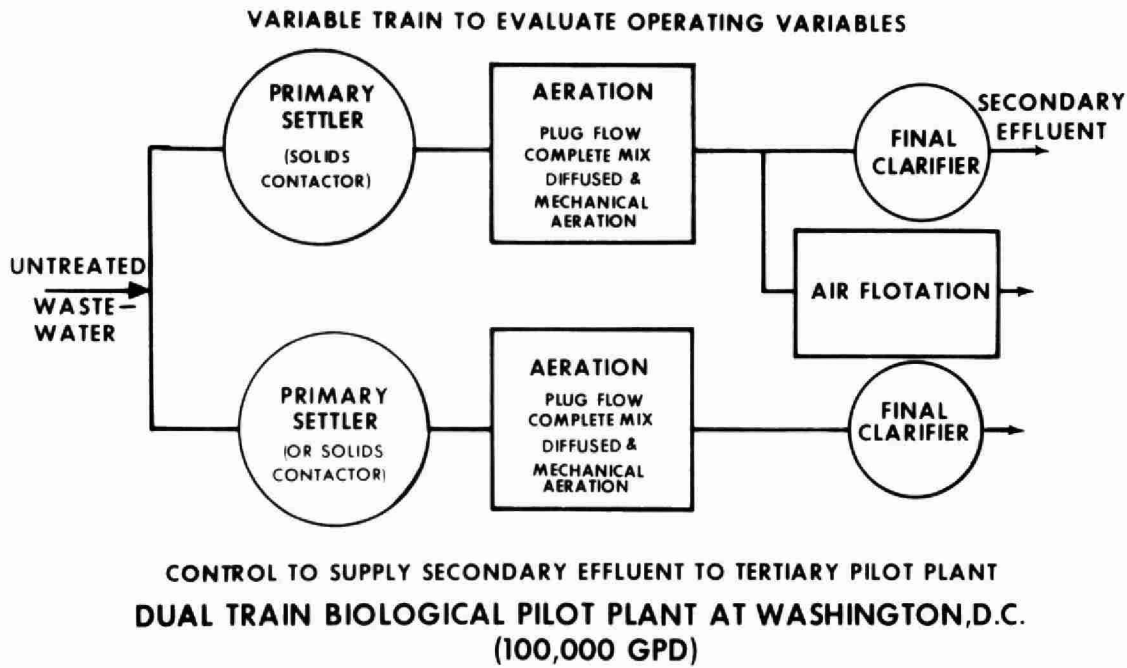
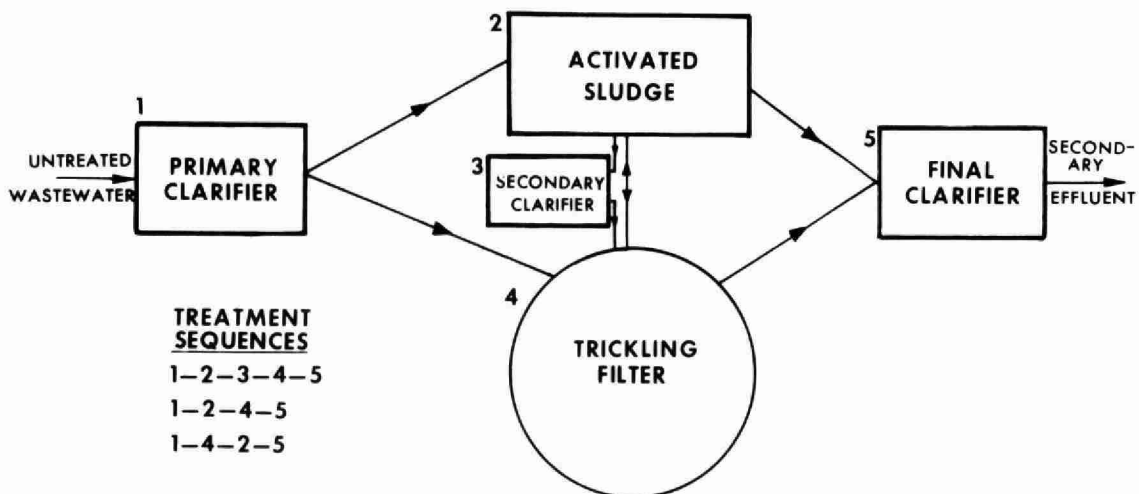


Figure 3

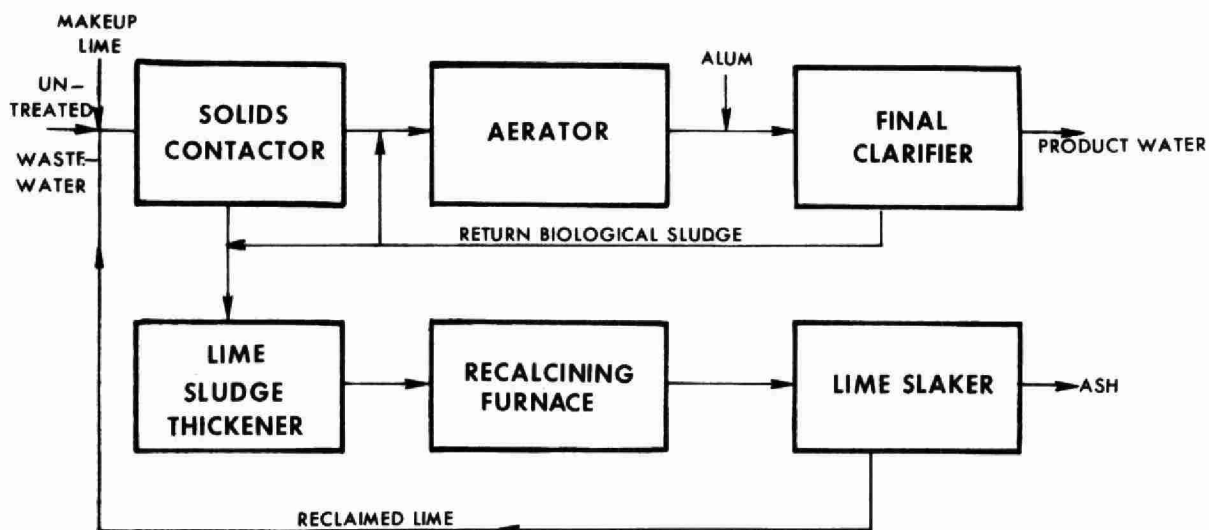
## FIGURE 3 TWO-STAGE BIOLOGICAL TREATMENT



RESEARCH AND DEVELOPMENT STUDY AT SAN BUENAVENTURA,  
CALIFORNIA(75,000 GPD)

Figure 4

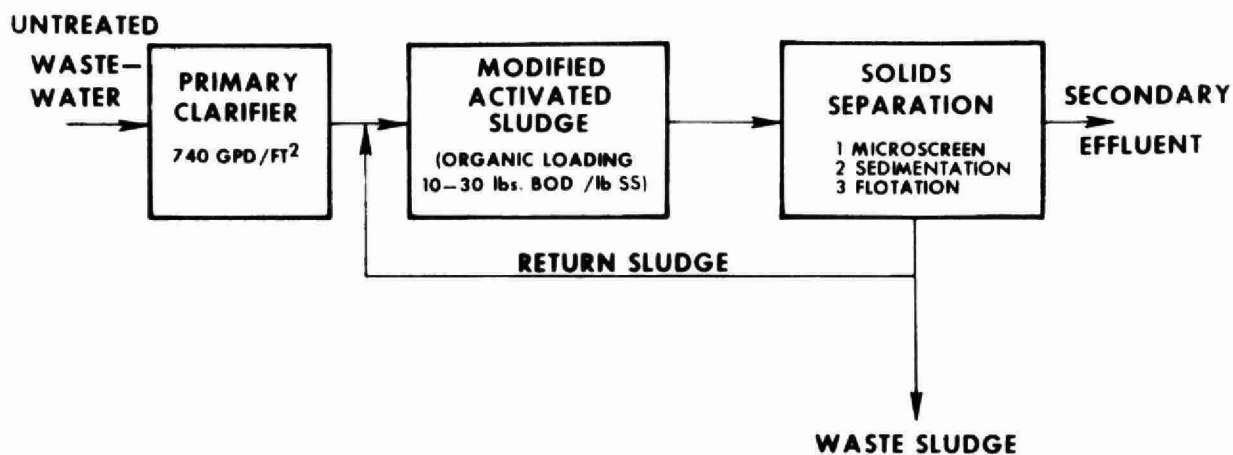
## FIGURE 4 PHOSPHATE EXTRACTION PROCESS (PEP™)



\* TRADEMARK DORR—OLIVER, INC. STAMFORD, CONNECTICUT

Figure 5

## FIGURE 5 HIGH-RATE NUTRIENT REMOVAL



RESEARCH AND DEVELOPMENT STUDY AT CHINO, CALIFORNIA  
(3.0 MGD)

Figure 6

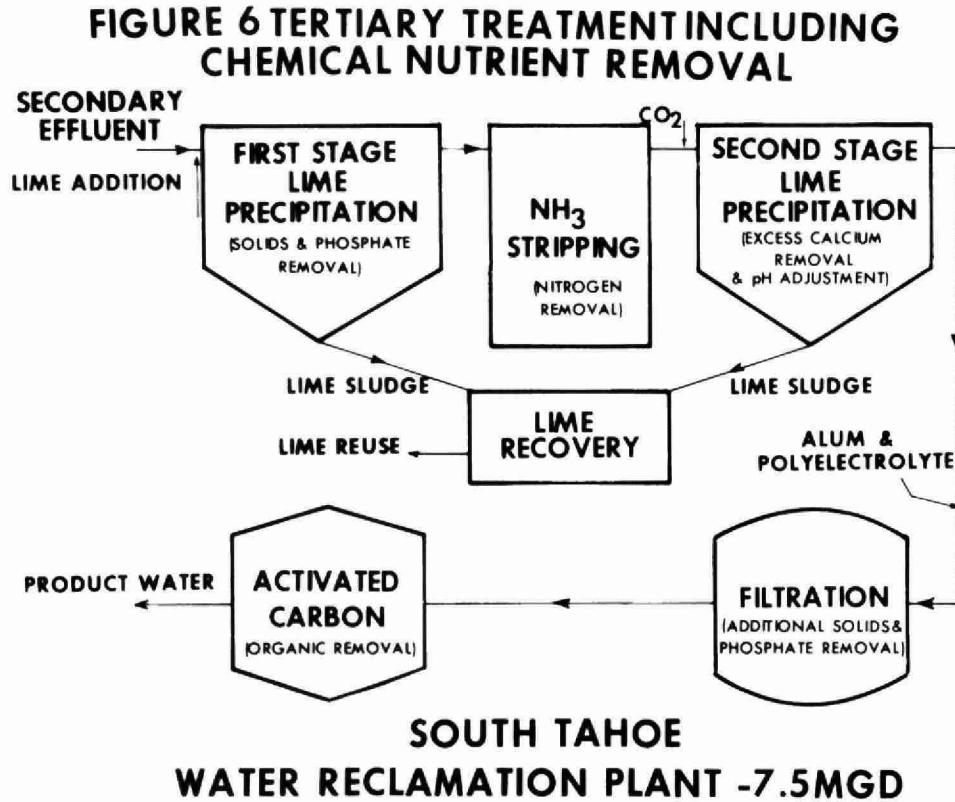
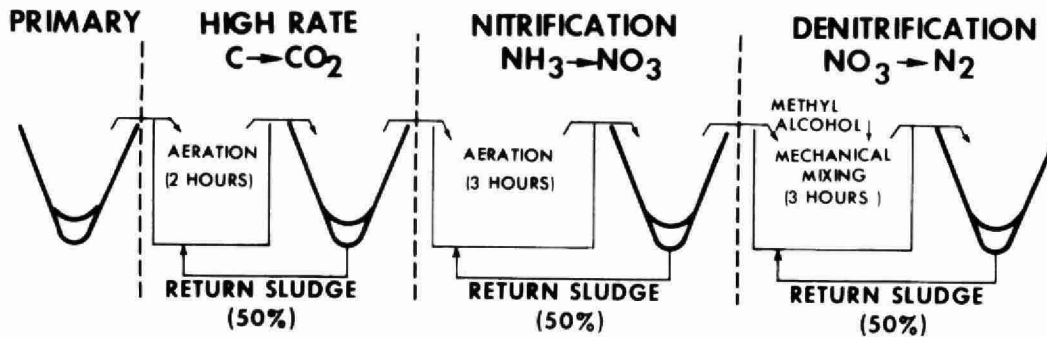


Figure 7

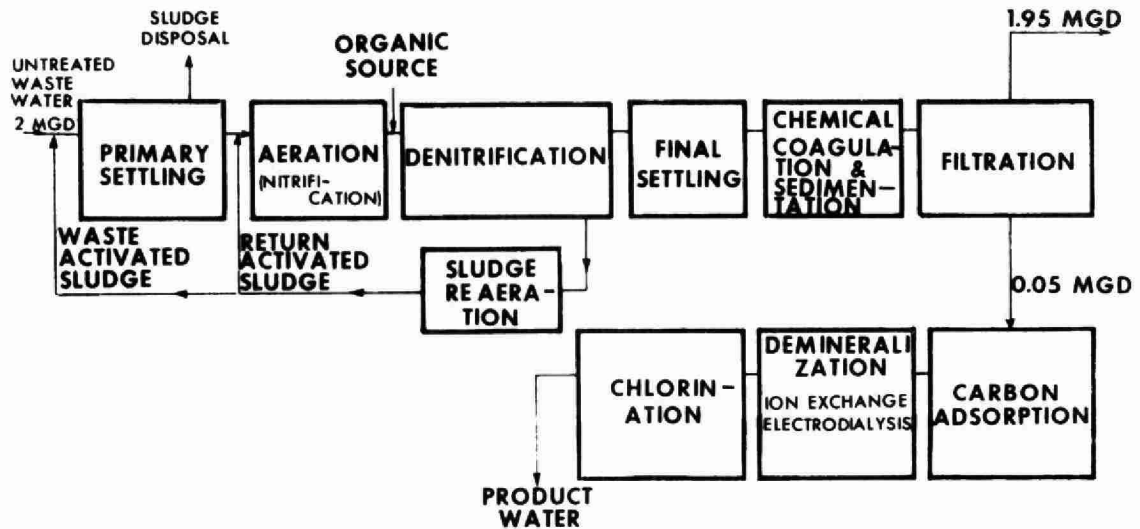
**FIGURE 7  
BIOLOGICAL NITRIFICATION  
& DENITRIFICATION**



**CWRL PILOT PLANT FACILITY 200 GPD**

Figure 8

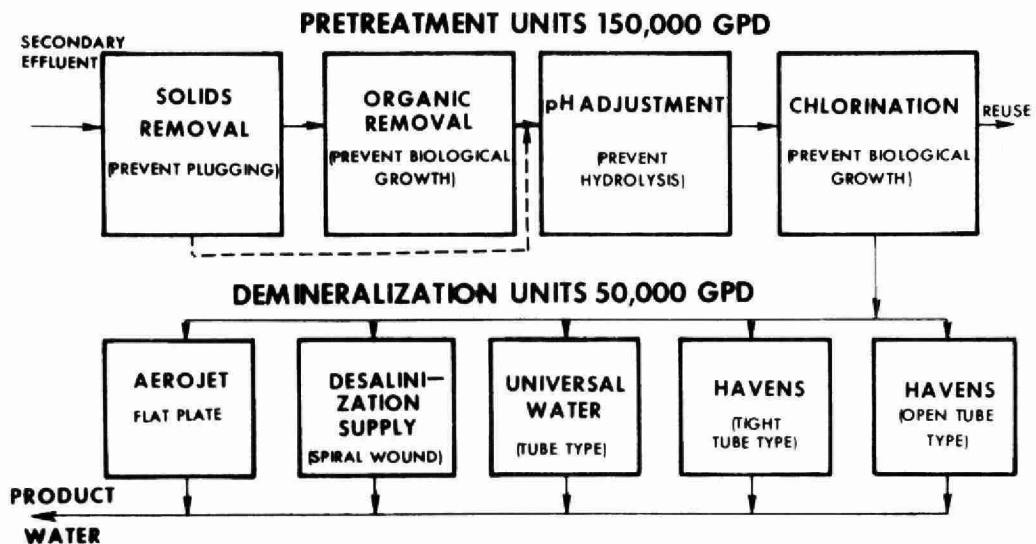
## FIGURE 8 COMPLETE CONVENTIONAL AND TERTIARY TREATMENT



RESEARCH AND DEVELOPMENT STUDIES AT SANTEE,CALIFORNIA

Figure 9

## FIGURE 9 DEMINERALIZATION BY REVERSE OSMOSIS WITH PRETREATMENT UNITS



RESEARCH AND DEVELOPMENT STUDY  
AT HEMET,CALIFORNIA

## SUMMARY

Pilot-plant and full-scale plant research and development studies of conventional process modifications and tertiary processes will serve to develop design data and provide more accurate and reliable cost-quality relationships for many individual and combined treatment processes. Basic research and laboratory-scale studies of other approaches to wastewater treatment are also being conducted. As new processes are developed, they will be evaluated in pilot plant and full-scale facilities. Technology is now available to solve the Nation's water pollution problems; however, at this time it cannot be stated that optimum design data are available for unit process selection. These data will be developed from current and future studies.

Waste characteristics vary widely with locations and each waste stream must be considered individually in selecting unit processes.

Costs of tertiary treatment will be high by present standards. Greatly increased expenditures will be required to eliminate pollution of our lakes and streams. Water reuse by industry and for nonpotable purposes will be necessary to reduce the financial burden. Potable water reuse by mixing with fresh water supplies is considered to be a distinct possibility in the future.

## APPENDIX I - REFERENCES

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DEPARTMENT OF SOIL SCIENCE  
UNIVERSITY OF GUELPH



"SEWER FLOW MEASUREMENT IN A LARGE  
INDUSTRIAL PLANT"

BY

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SR. CHEMICAL ENGINEER, UTILITIES DEPARTMENT  
POLYMER CORPORATION, SARNIA, ONTARIO.

How do you measure the flow of waste water in a small concrete lined ditch fifteen inches wide and six inches deep -- in one five feet wide and two feet deep -- or in an irregular excavated ditch six feet wide? How do you measure flow in a twelve inch diameter sewer running half full and readily accessible at a three foot deep catch-basin -- or in one five and a half feet in diameter, running nearly full and accessible only through a six inch diameter vent leading from a point fifteen feet underground? These are the kinds of problems one encounters in pollution control studies at a large industrial plant. With modern flow measurement technology --and a few million dollars -- the solutions are easy, but today I will describe how these and similar problems can be solved in a satisfactory manner with a minimum of expense.

The methods described will be those that have been successfully used in the Sarnia, Ontario, synthetic rubber plant of Polymer Corporation Limited. They were developed last year and using them two or three men can, in one eight hour day, make the twenty seven measurements necessary to establish the rates of flow of nine effluent streams and identify from which of seven processing areas they originate.

## The Polymer Survey and Its Problems

To permit accurate design of new pollution control facilities, to provide for future designs and to more accurately report our actual performance to the Ontario Water Resources Commission, a survey scheme was developed in the late Spring of 1967. The requirements were to measure all the important discharges to the river and to identify the sources of these streams by processing area. Each flow was to be established with an error of not more than 10%. This may seem like a large margin of error but is really a very practical limit. When designing for the future we can seldom predict our loads with this much accuracy and we can seldom design equipment within this limit. When making measurements for reporting to the Ontario Water Resources Commission such accuracy is very acceptable--some of the measured flows turned out to be half or double the previous "estimated" flows.

The Sarnia plant of Polymer Corporation is a completely integrated synthetic rubber plant originally built as part of the defense effort in 1943. Starting with waste light hydrocarbons from adjacent refineries and aromatic streams from the coking plants of Canadian steel mills most of the monomers required for rubber production are produced -- isobutylene, butadiene and styrene. Purchases of additional monomers (isoprene and acrylonitrile) permit the manufacture of almost every kind of synthetic rubber on the market today. In recent years we have also started to produce the important new ABS resins. Total production from the plant has increased from less than 90 million pounds in 1945 to over 500 million pounds in 1967--but mainly within the confines of the original plant and with only minimum additions to the sewer system.

The plant site itself fronts on the St. Clair River for about one third of a mile and extends back about one half of a mile to the east (Figure I). The original sewer system consisted of a main sewer, 66" in diameter, running down the middle of the plant to the river, a 54" sewer serving the feed preparation units and power house, and an oily water sewer draining selected streams from the hydrocarbon processing units to an A.P.F. type oil separator. Since then a 72" sewer has been added to serve the recently built stereo rubber unit, and several cooling water streams from the butadiene and copolymer rubber areas have been diverted to a ditch serving an old township drain. Coagulation facilities plus two large sedimentation basins have been added to facilitate removal of rubber fines from the copolymer rubber unit while two more A.P.I. type oil separators now serve the styrene and stereo rubber areas.



The main effluent material is cooling water used in the processes -- up to 150,000 gallons per minute in summer when the river water reaches its peak temperature. The total river flow is over 500 times as great so in the initial days of operation dilution was our main pollution control method. Our critical contaminants have turned out to be suspended rubber solids (latex and fine crumbs), oils and phenol -- hence the sedimentation basins and A.P.I. separators. Other less critical materials are suspended solids from boiler blowdown, dissolved solids such as salt and alum and dissolved organics such as carbonyls (acetone and ketones). A further stage of separation for rubber crumbs is presently under construction and equipment has just recently been delivered for a unit to remove and recover a large proportion of the dissolved carbonyls.

### Planning the Survey

Before planning any details of a sewer flow survey one must first become very familiar with two aspects of the subject -- flow measurement techniques and the details of your own sewer system. Standard hydraulic text books should describe most of the common measurements.<sup>(1 - 5)</sup> The Ohio River Valley Sanitation Commission has published a useful manual describing survey methods.<sup>(6)</sup> Most industrial instrument companies have literature describing measurement instruments and their use -- their salesmen are usually only too pleased to call on you.

To learn the details of your actual sewer system, it is necessary to study all relevant engineering drawings and then go out in the field and examine the actual installation. Unless your plant is brand new it is almost a foregone conclusion that the original drawings are no longer correct -- and it is a rare drafting room that can keep up with all the changes or even with those changes reported to it. Locations that on the drawings appeared to be ideal measurement stations will, when examined in the field, turn out to be less than suitable. A manhole will have been sealed off just last month to provide room for new equipment. The last tributary stream will join just downstream of the selected measurement station instead of just upstream as the drawings show. A leaking steam trap from somewhere unknown will have filled a catchbasin with fog so that you cannot see anything. There will most assuredly be such stumbling blocks but don't give up -- a few days becoming really familiar with the system will be time well spent.

Before choosing the measurement methods to be used, or even the streams to be measured, it is important that you set down the exact purpose of the survey. Do you want to know how much effluent your plant dumps into the public domain,

do you want to know where it comes from, or is your objective more limited -- to study only one unit in your plant? Establish your objectives and stick to them or everyone will get into the act and you will have an ever-growing list of measurements "that it would be nice to know".

The steps to be taken in laying out your plan are:

- 1) Set your broad objective.
- 2) Looking at an over all flow diagram of your system establish the minimum number of flows which will satisfy your objectives.
- 3) Looking at detailed engineering drawings of your sewers establish where these streams are accessible -- at a manhole, catch-basin, etc. Establish a tentative measurement technique.
- 4) Examine the locations in the field and determine that the measurement technique is practical. Change the technique if necessary or if on-the-spot examination indicates a better method is feasible. Provided that reasonable accuracy is possible, the easiest method to use is usually the best.
- 5) Some locations will not be satisfactory. Look for another access spot and examine it.
- 6) Some streams will not be easily accessible anywhere. Look then for two or more streams that can be measured separately and then have their measurements combined to give your desired measurement. Don't be surprised if there is a stream for which you can't see any practical method. If you have that "few million dollars" available there is undoubtedly a way to accurately measure almost any flow -- but there are certainly existing streams for which there is no economically practical way.
- 7) Plan for some extra measurements to establish or confirm the accuracy of your methods. If you measure all the tributaries of a stream also measure the total stream to see if it equals the sum of the tributaries. Perhaps you have faith in your methods but a check measurement is often good insurance.
- 8) Consider timing carefully, especially if you plan check measurements. Flow rates may vary significantly from one shift to another. Production schedules in multi-product units may result in widely varying day-to-day sewer flow rates. Unless flows are known to be steady for extended periods the measurements should be made quickly -- it may even be necessary to limit the number of streams to achieve this. Seasonal variations in cooling water temperatures can also cause large variations in flows and possibly determine at what time of year you should carry out your survey.

## Measurement Methods

There are many methods for measuring flow of fluids but I will not attempt to describe them all. Many involve expensive permanent installations while others require very little in the way of equipment. The survey that we made at Polymer avoided any new permanent installations and used less than \$500 worth of portable equipment -- all of which was already available in the plant. Our measurements were all either instantaneous readings at one point in time or average values over 15 or 30 minute periods. I will describe the methods we used and illustrate each with an actual example.

### Measurement of Flows Before They Enter Sewers

In some units for which only one sewer exists, it is possible to determine the sewer flow by measuring those streams which you know enter the sewer. For instance, all the effluent from our Styrene units drains away through one open ditch in which we wanted to know the flow. Nearly all the flow is cooling water -- any dissolved salts, hydrocarbons or other contaminants amount to less than 1% -- and all the cooling water enters the ditch. A Dall Flow-Tube<sup>(5)</sup> measures the cooling water for cost accounting purposes so all we had to do was read this meter and consider it as equal to the sewer flow. The Dall Flow-Tube has an error of not more than 2 or 3% so we had determined our sewer flow within 3 or 4% without making any special measurements.

### Measurement With a Current Meter

One of the most convenient instruments to use -- and we used it more than any other -- was the current meter as developed by Gurley, Haskell or Price.<sup>(3)</sup> This instrument, very similar to the weatherman's anemometer, measures velocity. To calculate flow rate you must obtain a weighted average velocity and a corresponding cross-sectional area of flow. By mounting the instrument on the end of a piece of 3/4 inch pipe we were able to manoeuvre it into sewers at depths as great as 15 feet. Our instrument had a bucket wheel 5 inches in diameter so in some of the small 12 or 15 inch diameter sewers we could not do any averaging of velocities but had to settle for one reading. The errors in such readings were probably close to our limit of .10% but these were small streams in our plant and not too important. A smaller model of the meter can be obtained which will permit a series of readings across the area of flow even in such small sewers. In larger sewers and ditches the instrument gave very satisfactory results. In a large concrete lined ditch 5 feet wide and 2 feet deep we made nine velocity measurements -- towards each side and in the middle at each of three depths. Repeat measurements a short

time later (during which time the flow should not have changed) gave an average velocity only 0.3% different from the first average. On one occasion when we were able to prepare balances around the unit from which this stream flowed (as 85% of the effluent) the input as measured by a Dall Flow Tube and three small orifice meters differed from the output as measured in three streams by only 1.2%. On another occasion the difference was only 0.4%.

#### Pitot Tube Velocity Measurements

In some sewers where the velocities were high -- usually at an outfall where velocities reached 8 or 10 feet per second -- it became rather difficult to hold the current meter steady in one position. A pitot tube fabricated from  $\frac{1}{4}$  and  $\frac{3}{8}$  inch tubing was much easier to handle and at these velocities was quite accurate. Our instrument -- a standard design as described in many texts (3,4,5) -- was strapped to a length of 1 inch by 2 inch wood and connected to a manometer by rubber tubing. For this shape of pitot tube the equation for velocity is

$$\text{Velocity (feet/second)} = 2,319 \sqrt{h}$$

where h = differential pressure, inches of water.

We would measure velocity at five or six points in a 30 inch diameter sewer flowing half full, recording differential heads of 12 to 16 inches of water. Cross-sectional area of flow was calculated by measuring depth, knowing the shape of the sewer was circular. We estimate that the maximum error in such flow measurements was not more than 3 or 4%.

#### Measurement of Free Discharge From a Pipe

The manual published by the Ohio River Valley Sanitation Commission<sup>(6)</sup> gives formulas for calculating the flow by free discharge of material from a pipe into the air. For a partially full horizontally discharging pipe the formula given is

$$\text{Flow Rate (USGPM)} = \frac{1800 AX}{Y}$$

where A = Cross-sectional flow area in pipe, square feet  
X = Horizontal distance, feet, from the end  
of the pipe in which the stream drops  
Y = Vertical distance, feet.

This method is not as accurate as some but we successfully used it where a hot water stream discharged from a 16" diameter horizontal pipe. The stream was at a temperature of 130 to 140°F so any spray created by

inserting a pitot tube or similar instrument was rather hazardous. We were able to measure the stream's trajectory; it fell 22 inches in a horizontal distance of 42 inches, without getting splashed. Assuming that the formula is accurate, our estimate of maximum errors in the individual measurements leads to an over all maximum error of not more than 5 or 6%.

#### Measurement of Flow Over Weirs

In some locations flow may be determined by measuring head over an existing weir. In A.P.I. type oil separators the outlet flow is over a horizontal weir so we merely had to measure the head and calculate the flow from one of the standard formulae.<sup>(1,3,4)</sup> For our suppressed weirs the formula is

$$\text{Flow (cubic feet/second)} = 3.33 WH^{1.5}$$

where W = Width of weir, feet

H = Head over weir, feet

In our main oil separator a permanently installed hook gage allowed measurement of the head with an error of less than 1% but fouling and corrosion on the metal weir plate probably limited accuracy so that errors of 4 or 5% were possible. Where hook gages were not installed we found a carpenter's square and a level adequate for reading the head to within 1/16 inch.

#### Measurement by Bucket and Stopwatch

Although this sounds like a very crude method, it can be very accurate if your "bucket" is large enough. Our most accurate measurements used this technique but the "bucket" was one of the settling basins for rubber solids. Periodically these must be emptied for cleaning so when one of the three parallel basins was empty and ready to go back into service all the flow was diverted into it and the filling time was measured. Volume of the 7000 cubic foot basin was easily measured within 1% and the time to fill (approximately 30 minutes) was also measured with an error of less than 1% even allowing for the few seconds necessary to simultaneously close off flow to the other basins and open the inlet to the empty one.

#### Measurement by Salt Dilution Techniques

If an inert chemical is added to a stream at a known rate and the stream is then sampled (after adequate mixing) and analysed for the chemical, flow rate of the original stream can be calculated. The formula used is



$$\text{Flow Rate (pounds per hour)} = R \frac{1 - A_2}{A_2 - A_1}$$

where R = Flow rate of added chemical, pound per hour

$A_1$  = Analysis of stream before addition,  
weight fraction of chemical

$A_2$  = Analysis of stream after addition,  
weight fraction of chemical

Common salt is an inexpensive, reasonably inert and soluble compound frequently used, hence the name salt dilution. We used salt as our chemical since large quantities of saturated brine were available for use in displacing hydrocarbons stored in underground caverns formed in salt beds underneath the plant. The key to success with this technique is an analysis method that is accurate and sensitive<sup>(7)</sup>. Unless you use a lot of the chemical it will be necessary to analyse with an accuracy of a few parts per million. Reasonably simple laboratory tests for NaCl fulfill this requirement.

At Polymer we used the method to measure two of the largest effluent streams just before they entered the river. In its last 1500 feet the 66" diameter sewer is accessible only at one point and then only through a 6" diameter vent pipe rising to the surface of the ground from the sewer 15 feet below. Brine from our storage distribution system was added through a hose to a catchbasin 1800 feet upstream of the 6 inch vent which served as our final sample point. The brine valve was adjusted to give the desired flow rate and was then allowed to drain into the sewer for half an hour to make sure equilibrium conditions were reached. Brine flow rate was measured by timing the period to fill a 55 gallon drum -- repeating this at the start and finish of the brine addition to be sure that the rate did not vary. When we first tried this method several samples were drawn from the sewer at 5 minute intervals to ensure that equilibrium conditions had been reached and also that an adequate distance had been allowed for complete mixing.

We were measuring a flow rate of 35 million pounds per hour in this sewer so a substantial brine flow rate was required -- approximately 50 gallons per minute of brine -- and even this gave only 170 parts per million of chloride ion in the sewer effluent. The brine flow rate was accurate within 2 or 3% while the laboratory analysis method may have been in error by as much as 5%. The resulting flow measurement could have been in error by as much as 5 or 6% but more care in the analysis or a better analysis technique could have improved this. Actually, a check measurement by another method showed only 1 1/4% difference.

## Indirect Measurement

The check measurement just mentioned was obtained by a much easier method than the salt dilution technique -- we merely added all the tributaries together. Such mathematical manipulation should not be ignored. It can be shown statistically that the percentage error in such a sum is usually smaller than in the individual measurements -- the random plus and minus errors tend to cancel each other out. Be careful if you try calculating a tributary by subtracting the other tributaries from the total flow, however -- the difference between two large but nearly equal numbers can have a very big percentage error. Any standard statistics text discusses this and can describe how to calculate the combined errors of more complicated methods. (8,9)

## Summary and Conclusion

There are many ways of measuring sewer flows and only a few of them have been described in this paper. It is important to realize, however, that there are simple methods that will work and give results accurate enough for most engineering purposes. None of the equipment is that difficult to use and the mathematics does not require an electronic computer. Measurement of industrial waste streams in your plant is going to be a legal necessity. Ordinary plant engineers and chemists will have to make these measurements because there is no army of experts waiting to take over. I hope that the techniques that have been described will help you in these future surveys. Most important of all, I hope that you will have gained confidence to tackle your particular problems. It is not that tough!

# POLYMER CORPORATION LIMITED - SARNIA PLANT.

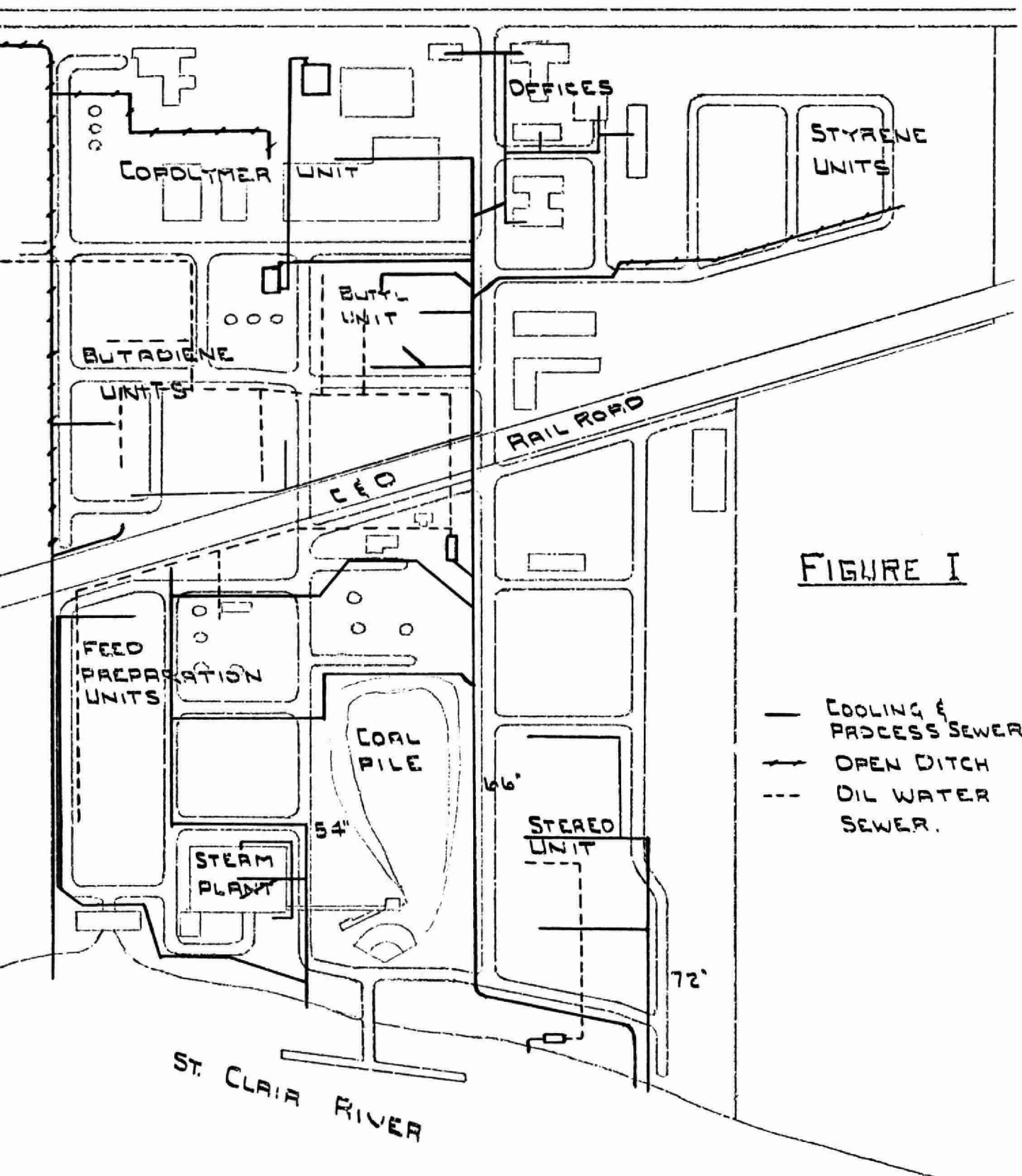


FIGURE I



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"THE ECONOMICS OF ALTERNATIVE METHODS  
OF WHEY DISPOSAL AT SOUTHERN ONTARIO CHEESE FACTORIES"

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FOREWORD

The subject of whey disposal is of particular relevance to Ontario since the Province accounts currently for 53% of Canada's total cheese production. For every pound of cheese, about ten pounds of whey are produced.

The structure of the industry is a contributing factor to the problem. When there were a large number of small individual operations widely dispersed throughout Southern Ontario, the disposal of whey was not a major problem. However, as the production per plant rose, and number of plants decreased, the problem became intensified.

Under present conditions, it appears that if only a few very large factories were involved, it would be economical for these to have whey processing facilities as a sideline. Although there is evidence of movement

toward fewer and larger plants, the range in size is still quite large and in the majority of cases, these plants do not have sufficient volume to warrant individual whey processing facilities.

This study, prepared at the request of the Milk Commission of Ontario, discusses some economic factors associated with whey and various methods of whey disposal and utilization.

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ACKNOWLEDGMENTS

Many people contributed to this study. Special acknowledgements are due to Dr. H. L. Patterson, and Mr. E. A. Haslett of the Farm Economics Branch; Mr. G. A. McCague, Chairman, Mr. J. L. Baker and Mr. J. Bain of the Milk Commission, Ontario Department of Agriculture and Food; and the members of the Advisory Committee on Cheese, who, at their meeting on April 11, 1967, suggested that every encouragement be given to this study.

Appreciation is expressed to Professor D. M. Irvine, Department of Dairy Science, University of Guelph, and Mr. H. A. Clarke, Assistant Director, Division of Industrial Wastes, Ontario Water Resources Commission. In addition, the assistance and co-operation by many representatives of the industry is appreciated.

INTRODUCTION

In ancient Rome, it was mentioned by Cato that whey was used for pig feeding.

In today's Ontario, whey has a great many more uses thanks to modern processes and advanced technology.

The cover of this report shows a youngster eating his mid-day meal. This illustration indicates some of the present uses of whey: the bread he eats may contain whey powder as does the processed cheese spread on his bread. Likewise, starting with soup and going on to dessert, with salad dressings, jams, cakes, cookies and a host of other foods in between, all could be made with whey products. Even the baby foods and some pharmaceuticals that our young friend may have used could contain processed whey derivatives.

The study of whey is of particular interest, since it involves the concept of changing a product that is often still of negative value to a product that could be of increasing worth to the Agricultural Economy in the years ahead.

TABLE I

CHEDDAR CHEESE PRODUCTION IN ONTARIO BY COUNTY AND DISTRICT12 months ending December, 1966\*

	<u>lbs.</u>
Elgin	407,447
Haldimand	32,238
Middlesex	2,677,497
Oxford	2,899,451
SOUTHERN ONTARIO	6,016,633
Bruce	1,645,350
Halton	581,027
Huron	188,552
Perth	2,844,200
Waterloo	1,460,828
Wellington	2,012,750
WESTERN ONTARIO	8,732,707
Durham & Northumberland	5,727,015
Hastings	9,120,370
Peterborough	463,000
Prince Edward	2,855,132
York	11,541
CENTRAL ONTARIO	18,177,058
Carleton	340,801
Dundas	11,850,032
Frontenac	1,568,308
Glengarry	4,056,827
Grenville	520,689
Lanark	1,114,413
Leeds	1,175,649
Lennox & Addington	4,771,491
Prescott	10,727,411
Renfrew	196,231
Russell	8,895,464
Stormont	11,051,980
EASTERN ONTARIO	56,269,298
Rainy River	1,754
Timiskaming	341,379
NORTHERN ONTARIO	343,133
THE PROVINCE	89,538,829
% change from last year	- 0.6

\*Source: Monthly Dairy Reports: Ontario Department of  
Agriculture and Food.

(1) DESCRIPTION OF CHEESE PRODUCING AREAS  
AND WHEY PROCESSING FACILITIES

Cheese Producing Areas\*

In Southern Ontario, as indicated on Map I, there are three major cheese producing areas. Going from west to east, these include:

- 1) In South-Western Ontario, the counties of Middlesex, Perth, Wellington, Waterloo, Bruce and Oxford. Most of the cheese factories are situated within a forty mile radius of Stratford.
- 2) In the Belleville Area, the counties of Durham and Northumberland, Prince Edward, Hastings, Lennox and Addington and Frontenac. Most of the cheese factories are concentrated within forty miles of the city of Belleville.
- 3) In the remainder of Eastern Ontario, the counties of Lanark, Leeds, Russell, Prescott, Stormont, Dundas, Grenville, Glengarry and Carleton. Most of the factories are within thirty miles of Casselman.

In addition to these major areas, there are cheddar cheese factories in various other locations in Southern Ontario. In Northern Ontario there are plants at Earleton and Thornloe. The relative importance of cheese production by county appears in Table I.

Whey Processing Facilities

In Ontario, current whey processing facilities are limited to the following seven locations:

1 Western Ontario

Three drying plants: at New Dundee (New Dundee Co-op Creamery), Harriston (Canada Packers, and Durham (Sunray Feeds).

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\*Unless otherwise specified, this report refers to cheddar cheese, and its by-products. Whey from cottage and speciality cheese manufacturing is not dealt with in this study.

### Whey Processing Facilities

In Ontario, current whey processing facilities are limited to the following seven locations:

1 Western Ontario

Three drying plants: at New Dundee (New Dundee Co-op Creamery), Harriston (Canada Packers, and Durham (Sunray Feeds).

2 Eastern Ontario

Four drying plants: at Wellington (Quinte Milk Products), Winchester (Aults), Plantagenet (Plantagenet Creamery) and Cornwall (Peebles).



(2) HISTORY OF WHEY DISPOSAL METHODS IN SOUTHERN ONTARIO

Cheddar Cheese production commenced in Ontario in 1864, with the establishment of the first factory near Ingersoll in Oxford county.

In the 1870's and 1880's whey from cheddar cheese factories was mainly returned to farmers as a feed for hogs. At that time, one survey showed that, in 1888, "eleven out of twenty-one factories in one area of Western Ontario fed whey to pigs near the factory; the other ten factories returned whey to the farmers". At that time, a rule of thumb used in whey feeding was 12 lbs. of whey equals 1 lb. of barley or rye".

The transport of whey was facilitated by the farmer delivering his milk by can to the cheese factory and returning to the farm with his can filled with whey. This involved minimal cost for transporting whey; and solved the disposal problem in a convenient manner.

The feeding of whey to hogs diminished in recent years because of:

1. Changes in feeding procedures.
2. New regulations that required the steam-cleaning of milk cans at the cheese factory. These became effective in the mid 1950's, and meant that milk and whey required separate containers.
3. Improved transportation procedures, whereby a milk trucker currently hauls milk from many producers to a factory, often by bulk: this replaced the former method whereby many farmers hauled their own milk in cans.

At the same time as whey utilization at the farm diminished, more whey was utilized at the factory, to make powdered whey, lactose, and lactalbumin: new drying installations were built and some existing operations were enlarged although the present capacity of the seven existing whey drying plants is by no means sufficiently large to handle all the whey that is produced in Ontario.

In Ontario, the drying of whey by rollers started in the mid 1930's. Grant Keeley of Silver Corners (near Listowel) was among the first to dry whey, and his product was used only for animal feed, as is the usual arrangements for roller-dried whey powder. The drying of whey into lactose and lactalbumin commenced in the 1940's, and it was followed by the spray drying of whey that was started after World War II in Eastern Ontario by Peebles at Cornwall.

In Western Ontario, the New Dundee Co-operative Creamery plant started drying whey in 1959-1960.

DECREASE IN NUMBERS OF CHEESE FACTORIES: 1901-1967.

At the turn of the century, in 1901, there was a total of 1,233 Cheese Factories<sup>1</sup>. This number decreased to 727 in 1933, 556 in 1941, 189 in 1958 and 127 in 1967. This decrease in the number of factories, through mergers, consolidations, or simply "going out of business" has a direct bearing on whey disposal. The decrease in number of the plants coincided with more cheese produced per plant, and therefore, more whey output per plant.

OUTPUT OF CHEESE FACTORIES

Cheese output in Ontario in 1966 was about six million pounds less than in 1946. Over the intervening years, production declined from 1946 to 1952 and then climbed to present levels.<sup>2</sup>

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<sup>1</sup> See Page 1, Cheddar Cheese Factories in Ontario, Nov. 1965. by Earl Haslett, Farm Economics, Co-operatives and Statistics Branch, in co-operation with the Dairy Branch, Ontario Department of Agriculture and Food.

<sup>2</sup> See Table III.

(3) THE PRESENT SITUATION: THE NATURE OF WHEY AND  
MAGNITUDE OF THE PROBLEM

Whey is the residual by-product in cheese making operations. It is described as "the greenish-yellow fluid remaining after the curd has been removed from either whole or skim milk", and has the following composition: 93% water; 4.9% lactose; 0.9% nitrogenous matter; 0.6% ash; 0.3% fat and 0.2% lactic acid.<sup>5</sup>

Because of its peculiar organic nature, all whey has a high B.O.D. (Biological Oxygen Demand) and is difficult to dispose of by conventional means.<sup>6</sup> It cannot be treated in septic tanks:<sup>7</sup> if left standing for any length of time it becomes quite rank and high in odour as its acidity increases. It also becomes an ideal growth-medium for bacteria. Due to these characteristics, raw whey is regarded as a serious pollutant and its disposal is receiving increasing attention from the Ontario Water Resources Commission, as well as other interested parties.

Whey is very bulky and found in large quantities where cheese is made. Out of every 100 pounds of milk going into cheese making, only 9 lbs. becomes cheese, the balance being whey.

Some idea of the magnitude of the problem of whey disposal in Ontario was brought to light by the findings of a recent survey by the Dairy Branch of the Ontario Department of Agriculture and Food.

The survey indicates that currently, the annual whey production in Ontario equals approximately one billion pounds, assuming a conversion factor of 90 lbs. of whey for every 100 lbs. of milk.

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5 E. O. Whittier & B. H. Webb. "By-products from milk". Ch.1. prg.4.

6 The effluent of a cheese factory handling 10,000 lbs. of milk per day is the equivalent of a city of 16,900 people from the standpoint of effluent produced.

7 The lactic acid which develops prevents proper breakdown of the organic materials in septic tanks, and they cease to function, becoming clogged with proteins.

The survey concludes, furthermore, that by far the greatest yearly volume of cheese production, investment in disposal equipment and yearly cost of disposal is in the "Eastern Ontario" region, that includes the counties of Renfrew, Lennox and Addington, and all others further east, within the province. The second largest cheese producing region is in central Ontario, that includes the counties of Hastings, Durham and Northumberland, Prince Edward and Peterborough, as its main area of cheese production. On a regional basis, the total appears as follows:

TABLE IV                      REGIONAL WHEY PRODUCTION ONTARIO, 1966<sup>8</sup>

Ontario Region	No. of Plants	Volume Yearly	Peak Volume per day	Investment	Annual Expenditure
		'000 lbs.		'000 \$	'000 \$
West	14	164,180	804	54	10
South	13	73,224	364	30	8
Central	27	157,025	1,068	56	11
East	68	771,259	4,613	202	88
North	2	17,651	91	1	-
	124	1,183,339	6,940	343	117

<sup>8</sup>Source: Survey conducted by Dairy Branch, Ontario Department of Agriculture and Food.

In the Dairy Branch survey, a considerable number of cheese factories, representing approximately 50% of the volume, indicated they had an "unsatisfactory" system of waste disposal. This problem exists in spite of the fact that in 1966 some \$120,000 was spent by the cheese factories collectively to dispose of their whey.

Further evidence of the problem and its magnitude is shown by a recent survey by the Ontario Water Resources Commission.<sup>11</sup> This survey summarizes the current situation regarding waste disposal practices in Ontario Cheese Factories.

<sup>11</sup> see Appendix I - letter from Division of Industrial Wastes, Ontario Water Resources Commission, May 15.67.

TABLE V.      ACCEPTABILITY OF WASTE DISPOSAL PRACTICES  
AT ONTARIO CHEESE FACTORIES - 1966

	<u>No. of Plants</u>	<u>Percent.</u>
currently acceptable waste disposal practices.	52	40
unacceptable waste disposal practices.	37	29
seasonally acceptable waste disposal practices.	30	23
current status unknown, unidentified or temporarily suspended.	9	8
	<hr/>	<hr/>
TOTAL	128	100
	<hr/>	<hr/>

The Ontario Water Resources Commission also gave a further commentary on the waste disposal plans by the 37 plants with unacceptable waste disposal practices. (Table VI).

TABLE VI.      FUTURE PLANS FOR WASTE DISPOSAL AT ONTARIO  
CHEESE FACTORIES, 1966

	<u>No. of Plants</u>
Plans for control under consideration	15
Facilities for control under construction	3
No facilities planned or under construction	<u>19</u>
TOTAL	<u>37</u>

The seriousness of the problem is evident from the foregoing summary, which indicates that 29% of Ontario's cheese factories have currently unacceptable waste disposal practices. In addition to these 37 plants, there are 39 more that have seasonally acceptable waste disposal practices

or are unidentified, suspended or alternatively fail to have currently fully acceptable practices.

A further analysis of the magnitude of the problem can be made when examining data concerning the annual production of whey products in Ontario. (Table VII)

TABLE VII                      WHEY UTILIZATION,      ONTARIO    1965 - 1966

Product	1965 '000 lbs.	%	1966 <sup>12</sup> '000 lbs.	%
Cheddar cheese production <sup>13</sup>	89,994	-	89,293	-
Whey from cheddar cheese <sup>14</sup>	899,940	100	892,930	100
Whey powder <sup>15</sup> (as whey equivalent).....	336,880	37	332,800	37
Remainder	563,060	63	560,130	63
Estimated 25% of remainder used in whey cheese, whey butter, lactose and lactal- bumin <sup>16</sup> .....	140,765	16	140,033	16
Balance fed to hogs and otherwise disposed of.....	422,295	47	420,097	47

<sup>12</sup> Preliminary

Sources:

<sup>13</sup> Table 81, Agricultural Statistics for Ontario, 1966.

<sup>14</sup> Based on conversion factor used in Wisconsin Study, op.cit. see p.10, "10 pounds of whey per pound of cheese".

<sup>15</sup> Table 84, Agricultural Statistics for Ontario 1966.

<sup>16</sup> Estimates were used as no production statistics on lactose, and lactalbumin are published, because less than three firms are engaged in their manufacture.

From Table VII, it is apparent that there is a large balance of unused whey in Ontario, more than 400 million pounds annually, and much of this unused whey presents a serious disposal problem both to the cheese manufacturers, and to the community at large.

If all of the 400 million pounds of liquid whey could be dried into powder, this would yield about 20 million pounds of whey powder at the rate of 5¢ per pound of dried whey. This would have a gross value of one million dollars.

However, the proportion of unused whey that can be economically utilized is dependent upon the costs of assembly, processing and distribution in relation to the market value of the end products. The feasibility of certain alternative uses of whey is discussed in the following section, as well as the necessary requirements that must be met before economic utilization of whey can be realized.

#### (4) REQUIREMENTS FOR ECONOMIC WHEY DISPOSAL

##### The Value of Whey:

The gross value of 100 lbs. of skimmed liquid whey varies in the range of 25 cents to 35 cents, based on a value of 5 cents per lb. for the dried whey, and recoverable solids content ranging from 5.0 to 7.0 lbs. per cwt. This gross value would be appreciably higher if the liquid whey is converted into lactose and lactalbumin or "human grade" dried whey powder.<sup>17</sup> The most valuable constituents of whey are fat, lactose and protein.

##### Fat:

The proportion varies according to the butter fat content of the milk. Many cheese factories recover the fat by separation before disposing of the whey. Whey fat is often referred to as "whey cream", and is used to make whey butter. In Ontario in 1966 some 3,051,000 lbs. of whey butter were produced.<sup>18</sup> Approximate wholesale value of 50-55¢ per pound.

##### Lactose:

About 70% of the solids of whey are lactose. In Ontario there are currently only two factories that produce lactose (Quinte Milk Products at Wellington, and Peebeles at Cornwall), and for this reason, no statistics for lactose are available for publication. Refined lactose is used primarily in pharmaceuticals and infant foods and, to a limited extent, in the manufacture of penicillin. The lactose in whey contributes to its value as a source of energy when used as food.<sup>19</sup>

##### Protein:

About 12% of the solids of whey are protein. This helps to make whey useful as a livestock feed. Whey protein, as a separate product has been considered of minor practical importance in the utilization of whey, largely because of the

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<sup>17</sup> Prices for spray-dried whey powder, lactose and lactalbumin are not published, but are assumed to be appreciably higher than the 4¢-5¢ per lb. for roller-dried whey powder. "Human grade" whey powder has been known to have a market value approximately one-half the price of skim milk powder.

<sup>18</sup> Source: "Agricultural Statistics of Ontario". op.cit.

<sup>19</sup> See Pages 11 and 295, "By-Products from Milk" op.cit. for a more detailed discussion on Lactose.



relatively small quantities present. The nutritional value of whey protein is high, and therefore it is a valuable component of whey products that are destined to be used as food or feed. When whey is to be disposed of as sewage, then the whey protein, which accounts for about one half of the biological oxygen demand of whey, has a definite negative value.

The processes necessary to isolate the valuable constituents of whey are, in most cases, very costly. In fact, so much so that much of the whey has been considered as a valueless product, in Ontario. Contributing most significantly to the problems of profitably utilizing whey are:

- (i) The biologically active nature of the product.
- (ii) The bulkiness of whey, and its low content of valuable solids.
- (iii) The seasonality of its production; most whey is produced in the spring and summer.
- (iv) The high cost of transporting whey from cheese factories to a processing plant.

The end products of whey are numerous and varied as shown on Table IIX, and some of these products that involve sophisticated procedures place an ultimate value on whey that is in excess of the 5¢ per pound level. It is claimed that whey, in its dried form, has some unique characteristics that make it of particular value in such products as frozen foods, ice creams, sherberts, baked goods, instant potatoes, mayonnaise, french dressings, jams, and related foods.<sup>20</sup>

It has been stated that, "properly processed sweet fluid whey does not seem to mash flavours normally used in ice cream and other frozen desserts.<sup>21</sup> claims have been made that whey usage enhances flavour".<sup>21</sup>

There appears a growing recognition of the value of whey in various segments of the food processing industry.

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<sup>20</sup> "Improve Your Products with Whey Solids". "Food Processing", August, 1965 issue.

<sup>21</sup> "How Whey Solids Can Lift Your Profit Two Ways" Food Engineering, Sept., 1960. "What Whey Is All About", Ice Cream Field, April, 1959.

In order to have economic whey disposal operations, several possibilities exist - each with different requirements.

#### 1) A Roller-drying Operation

Success of individual enterprises will depend on the selection of related equipment of a scale in proportion to the amount of whey to be processed. At many plants, storage facilities both for the raw whey and the dried product are inadequate for a whey processing enterprise. A basic requirement in roller drying is a plentiful supply of steam, because roller drying is an inefficient use of heat and in many situations added boiler capacity may be needed. To make such an operation financially successful, these resource requirements must be satisfied at a cost below the market value of the end product.

#### Costs of Roller-drying operation

Within the limited time available, it has not been possible to ascertain detailed processing costs for whey powder in Ontario. A study conducted at the University of Wisconsin, published in 1965,<sup>22</sup> provides a useful guide to the specific costs involved. These figures were compared, insofar as possible, with sources in Ontario.

#### Initial Costs

A roller-drying plant with a capacity of 3,500 lbs. of raw whey per hour could be built at a cost of \$40,000 - \$50,000 including used storage tanks and a used roller dryer, and the balance of the equipment being new. This cost can be reduced by approximately 30% if the existing cheese plant already has the necessary space to accommodate the roller dryer. On the other hand, if all the items of equipment and building must be new, then the costs would be at least 80% higher.

#### Operation Costs

A roller-drying plant as described would entail a daily fixed cost of approximately \$21.00, (not including labour) and variable costs of about 22 cents per cwt. Operating at the maximum of 22 hours per day, the fixed costs would be about 3 cents per cwt., and the total approximately 25 cents per cwt. of raw whey. The cost per

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<sup>22</sup>"An Economic Analysis of Whey Utilization & Disposal in Wisconsin", University of Wisconsin, 1965. See p.47.

lb. of whey powder at a particular level of operation would vary according to yield of powder per cwt. of raw whey. At 5 lbs. per cwt. the cost would be 5 cents per lb.

#### Comments

Keeping in mind the limitations of the above data, it appears that roller-drying of whey is, at best, a marginal operation. Since the end product of roller-dried whey is hygroscopic, its use is almost exclusively as animal feed. Roller-drying is not an efficient user of steam; in order to improve its efficiency, it is useful to condense the whey to 50% of its original water content, but this adds drastically to the original investment. (see No. 3)

#### 2) A Spray-drying Operation

The basic requirements for successful spray-drying are similar in principle to those of roller-drying. The main difference is size of investment and scale of enterprise. A greater supply of fuel, and a higher degree of skilled labor experienced in spray-drying operations is required. In addition, a sufficient quantity of first-quality whey is needed so that the spray-dryer can operate at capacity and produce a top quality product that is suitable for human consumption. Such a product commands a higher price than second-grade<sup>23</sup> whey powder used for animal feeds. In order to obtain adequate supplies of first quality whey suitable for spray-drying, the whey must originate from first quality milk handled under the best conditions and in stainless steel holding tanks, not cast iron containers; it must also be kept "sweet" and it is preferable for the whey to be pasteurized, clarified and cooled prior to processing.

#### Cost of Spray-Drying

Spray-drying of whey can be readily adapted to produce a product that is non-hygroscopic and acceptable for human consumption. As in the spray-drying of skim milk, such an operation requires a heavy investment in plant and equipment. The spray-drying of whey differs from that of skim milk because of the high lactose content of whey. Two variations from the skim milk drying process have been developed to overcome the instability caused by the high lactose content of whey. Both methods involve a procedure for crystalizing the lactose and the resulting product is a stable, non-hygroscopic powder.

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<sup>23</sup> It is understood that the Government of Canada is currently developing grade standards for whey powder.

### Initial Costs

A spray-drying plant with a capacity of one million pounds of whey per day (21 hours) involves approximately \$1,200,000 including all new equipment, based on the findings of the University of Wisconsin. A spray-drying plant with a capacity of 500,000 lbs. (17 hours) involves approximately \$700,000. Almost 50% of these costs are buildings.<sup>24</sup>

### Operation Costs

A spray-drying plant of one million pounds daily capacity has a daily fixed cost of \$700 (including labor), and variable costs of about 8¢ per cwt., giving a total of approximately 15 cents per cwt. of raw whey. At a yield of 5 lbs. of powder per cwt. the cost would be about 3 cents per lb.

For a spray-drying plant of 500,000 lbs. of daily capacity, estimated fixed costs are about \$500 (including Labor) and variable costs of about 8¢ per cwt. of raw whey. Operating at less than capacity the smaller plant is relatively more efficient (according to the Wisconsin Study) and is only at levels of operations above the maximum capacity of the smaller plant, (700,000 lbs.) that the larger plant becomes relatively more efficient.

### Comment

There is little doubt that spray-drying of whey is currently one of the most efficient processing methods for large volumes of whey. It should be noted that transportation charges have not been included in this chapter. Further discussion of the costs involved in the transportation of whey is in the following section.

Many of the processes covering spray-drying and related operations are protected by patents. Any new spray-drying operation should study the patents covering any of the new products being considered. Spray-dried whey powder is considered by some segments of the food processing industry to be of growing importance as a basic ingredient of many products. As the end use of the product generally determines its price, it is expected that spray-dried whey powder will produce greater returns than the roller-dried powder that is generally restricted in use to animal feeds.

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<sup>24</sup> These estimates are applicable to Ontario, according to information received from a major supplier of equipment to the Dairy Industry. One estimate gave the cost of a million-pound dryer at \$1,055,000 in Ontario.

### (3) Central Processing of Whey: A Transportation Problem

There are some 124 cheddar cheese factories in Ontario and to establish individual processing facilities at each plant would be difficult to envisage, because of the costs involved and the relatively small amounts of whey produced at some of the older, smaller cheese factories.

It may be feasible to transport first quality whey by truck from surrounding cheese factories to a processing operation that is centrally located in a cheese-production region, and has sufficient capacity to handle the whey.

The basic requirements are a sufficient supply of sweet whey that has been properly handled and transportation costs low enough to allow for a margin above the processing and drying costs. A uniform or constant supply of whey year round is desirable as it would allow a proper utilization of capacity.

The crux of the problem lies in the costs of transportation, since whey is such a bulky product and consists of 93% water. To overcome this dilemma, a solution must be found in the form of a highly efficient transportation system. This requires careful planning of truck capacity and routes to maximize the use of equipment and minimize the distance covered.

If great distances are involved between the cheese factories and drying plants, the physical separation of the concentration and drying facilities may be desirable. The importance of short hauling distances was demonstrated in Wisconsin, where it was found that a 50 mile radius is the maximum distance of economic transportation of raw whey. Beyond this distance, it is apparently cheaper to concentrate the whey to 40% solids content prior to hauling to the drying plant.

Costs involved in operating a 300,000 lb. per day concentrating plant were estimated at 15¢ per pound of solid, for a concentrating plant in Wisconsin. Costs of steam, depreciation of equipment, water, electricity, and labour were included.

The initial outlay for a concentration plant is in the range of \$200,000 to \$300,000. There may be excess concentrating capacity in the Dairy Industry. Suitability of expanding existing dairy facilities as an alternative to building new facilities should be explored, because of possible savings.



In order to be a feasible alternative, concentrating facilities should be in reasonably close proximity both to the sources of whey and to facilities. An advantage of concentration of whey is to save transportation costs if long distances are involved in reaching a whey processing operation, according to the Wisconsin study. The decentralized concentration arrangement may reduce shipping costs by as much as 84% as compared to hauling raw whey, if the whey is concentrated to 40% solids. Reduction in costs is due primarily to lower fixed costs by maintaining a smaller fleet of trucks to haul concentrated whey. For example, to haul 400,000 lbs. of raw whey to a central drying plant would require nine loads per day. If the product were concentrated, it could be hauled in two loads.

Based on the location of cheese plants in most of Ontario, the concentration of whey does not appear to be practical, unless it involves the sharing of concentrators with other Dairy products. As indicated, in the description of cheese factory locations in Ontario, most of the plants in the three main areas of production are concentrated within a 50 mile radius of a central point. (Pg.1<sup>25</sup>)

#### 4) Feed Whey to Hogs

The feeding of whey to hogs was the primary method of whey disposal during the early stages of the industry.

Liquid whey is considered to be a valuable supplement for hog feeding when properly used. Professor R. P. Forshaw, of the University of Guelph, has commented that: "Whey is worth one-half the value of skim milk as a hog feed, its protein is of high quality", and that "whey is a good dietary source of Riboflavin, in all, a useful additive towards a well-balanced ration".

In Ontario there is currently no published data available on the amount of whey returned to farmers. In Wisconsin, 89% of the cheese factories gave free whey to farmers. In 1962, this was the most prominent method of whey disposal and many of the factories considered this as a service in order to keep their patrons.<sup>26</sup>

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<sup>25</sup> Decentralized concentration may be practical if viewed from the standpoint of expanding existing processing facilities.

<sup>26</sup> "An Economic Analysis of Whey Utilization and Disposal in Wisconsin". p.15, op.cit.

One advantage for the cheese factory when returning whey to farmers is that it avoids heavy capital expenditure on processing equipment.

However, many farmers consider the feeding of whey to hogs impractical under present-day conditions. The basic difficulty is attributable to:

- a) Changes in hog feeding procedures.
- b) Seasonality of whey production.
- c) High costs of handling whey.

The feeding of whey to hogs, although declining in importance, is still a substantial outlet for whey. In some places it may warrant attention as an alternative to the present disposal program. It may be advantageous for a cheese factory in a remote area to pump its surplus whey with plastic pipe to a nearby hog farm as a means of disposal. A large cheese factory in St. Isidore de Prescott in Eastern Ontario currently uses this method to dispose of the bulk of its surplus whey. A word of caution may be in order regarding the waste disposal problem because a large hog enterprise creates large amounts of waste material (manure and urine) that produce undesirable odours and become a potential pollutant, unless properly disposed.

#### 5) Using Whey as an Agricultural Fertilizer

In theory, the utilization of whey as fertilizer has potential as a disposal method. In addition to being food for crops, whey also improves the soil structure; similar to its use as a feed for hogs, it precludes the need for extra plant equipment.

A ton of whey contains about three pounds of nitrogen,  $3/4$  lbs. of phosphorus, and three and a half pounds of potassium: in addition there are small quantities of minerals. If a farmer were to buy these nutrients in commercial fertilizers, the cost would be about 60¢.<sup>27</sup>

Three tons of whey contain about as much plant food as one ton of manure. On this basis, the value of whey to a farmer when used as a plant food may be as much as 3.4¢ per cwt. In addition, the application of whey to croplands has been facilitated recently by new equipment designed to handle liquid manure in large quantities.

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<sup>27</sup> Interview, May 1967, with representatives of Soils Department, University of Guelph.

One serious drawback to use of whey as fertilizer is that it is not a year-round solution: there are only limited times of the year when fertilizer can be applied to the soil.

The value of 1,000 gallons of whey has been calculated to be: Nitrogen, \$1.40: Phosphorus, \$.80: Potassium, \$.95 for a total value of \$3.15. This value is too low to make whey very attractive as a fertilizer in the light of the cost of hauling of whey, as well as its bulkiness, and the need to purchase equipment before it can be effectively utilized.

The potential use of whey as fertilizer cannot be ruled out altogether, since it may be a less costly way for a small cheese factory to dispose of some of its surplus whey, than some of the other alternatives that involve the outlay of considerable funds for equipment and facilities.

6) Use as a Raw Material for Lactose, Riboflavin and Related Products.

It is possible to manufacture lactose and lactalbumin from whey. The processing involves usually separation of whey protein by heat coagulation from the lactose, and drying each of these components.

In Ontario, currently two plants, at Wellington and at Cornwall, are involved in manufacturing lactose and lactalbumin and this use of whey holds considerable promise. In view of the scarcity of data regarding costs involved in production, it is difficult to determine the relative attractiveness of this disposal method, if compared to regular spray drying operations of whey.

According to one authority<sup>28</sup> "Many substances are reported to have been produced by fermentation of crude lactose. Those produced in yields sufficient to warrant consideration for commercial production from whey include, ethyl and butyl alcohols, butyric, citric, acetic, propionic, and lactic acids...riboflavin and yeast. Lactic acid and riboflavin are produced commercially by fermentation of whey. Butyl alcohol and acetone are by-products of the production of riboflavin.

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<sup>28</sup> see: E. O. Whittier & B. H. Webb, p.31, "By-products from Milk". op.cit.



The lactalbumin is used as animal feed, and the refined lactose is primarily used in pharmaceuticals and infant foods.

#### Use as a Raw Material in Beverages

In Europe a high quality liquid whey is used as a beverage. Flavoring in the form of natural herbs and aromatics is added to the whey, and the product is processed into a soft drink. It is understood that this new beverage has found consumer acceptance in Western Europe, and may hold promise for the North American market.

Samples of the beverage have been tested for flavour and colour during the course of this study and appeared to be quite pleasant and refreshing, and the product was attractive in appearance, somewhat similar in colour to pale ginger ale.

In theory, the concept of transforming liquid whey from a noxious industrial waste into a palatable and refreshing liquid has considerable appeal.

Insufficient data regarding costs of this process is currently available to determine if a whey beverage could be advantageously marketed to absorb substantial amounts of Ontario's surplus whey.

Since the ingredient of a whey beverage would be more costly than those of carbonated beverages, such as the cola drinks or the ginger ales, the future of a whey beverage might have more potential in a speciality market. If it could be shown that the whey beverage has significantly superior nutritive qualities, the prospect of its marketability would be enhanced.

#### 8) Use as a Raw Material for Vinegar

It is possible to manufacture vinegar from whey. In fact, in Western Europe, a whey-based vinegar called "Lacta-Vinegar" has been on the market since 1952. Apparently its sales have increased appreciably and currently represent 5% of the total consumption of vinegar in Switzerland. The vinegar is made from high-quality whey, according to its manufacturer.<sup>29</sup> It is necessary to concentrate the whey in order to obtain, after successive stages of fermentation

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<sup>29</sup> see: Bourgeois Freres et cie, S.A. "A Very Interesting Supplementary Product: Lactavinegar." Ballaigues, Switzerland.

(lactic, alcoholic, and acetic) vinegar with an acidity of 4.5% to 6%.

Samples of vinegar have been tested for flavour and appearance during the course of this study. The vinegar appeared to be quite palatable.

To transform surplus liquid whey into vinegar has interesting possibilities, especially since the whey-based vinegar contains Vitamins B<sup>1</sup> & Riboflavin, aminoacids, lactic acid and all the soluble salts of milk. It is claimed to be particularly suitable for children and people with sensitive stomachs. Unfortunately, insufficient data regarding costs of this process is currently available to determine whether a whey vinegar could be advantageously marketed in Canada. The question remains, whether or not sufficient quantities of whey vinegar could be used both by the Industrial Vinegar market, and by the retail market in order to absorb a substantial volume of Ontario's surplus whey.

#### 9) Precipitating the Solids of Whey

In the 1951 issue of the Canadian Journal of Technology, "The Precipitating of Whey Proteins Using Waste Sulphite Liquor"<sup>30</sup> was discussed. Briefly, this procedure has shown that: "Waste sulphite liquor may be used as a precipitant for whey proteins. The whey does not have to be heated nor the acidity of the whey adjusted when it is a by-product in the manufacture of acid coagulated casein. The lignin-protein complex can be separated easily from solution and readily dried. The method seems to be a more convenient means of recovering whey proteins than the heat coagulation method, when it is to be used as a protein supplement in animal feeding."

In theory this method might be feasible in areas close to the pulp and paper industry, where large amounts of waste sulphite liquor might be readily available. However, it is by no means certain that this method could have practical disposal significance because the above process only precipitates the proteins, and does not eliminate all the lactose in whey.

In addition, it has not been shown that the value of the precipitated proteins would be great enough to support the operation. It is understood that some research is

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<sup>30</sup> By John H. Hare & Bruce E. Baker, Chemistry Department, Faculty of Agriculture, MacDonald College, McGill Univ.

currently in progress to isolate or concentrate the solids in various liquids that have a high water content. If this research proves successful, it could provide an added solution in the disposal of surplus whey.

#### (10) Use as Sewage

In the absence of any economic treatment facilities, many cheese factories have regarded whey disposal simply as a sewage problem. Hence, if the cheese plant was situated on a municipal sewage network the whey would accompany the wash-water into the sewer.

In addition to some whey from cheddar cheese making, it is understood that most of the whey from cottage cheese manufacturing frequently goes into municipal sewers.

From a disposal standpoint, the municipal sewer system is a better destination for the whey than polluting a nearby stream, a final alternative that is obviously unsuitable and in contravention to the regulations of the Department of Health and the Ontario Water Resources Commission. The use of whey as sewage has many drawbacks: it taxes a municipal sewage treatment plant very heavily, since whey is very difficult to treat. Its application, in any case, is very limited since most cheese factories are located in rural areas and removed from a sewerage network. In addition, another drawback is that it renders worthless a potentially valuable product.

Closely allied to sewage is the disposal of whey by spraying it on lands adjacent to the cheese factory. It is suspected that such a disposal procedure may lead to "Bacteriophage" problems. The consequence of bacteriophage potentially is destruction of the cheese starter, with heavy financial losses to the manufacturing operation. Another problem with spraying whey on land is that it can only be done seasonally, and excess concentrations of whey can lead to "puddling" and destroy the vegetation. If great care is taken and if the soil is suitable, this method of whey disposal can provide an interim solution. The use of lagoons, some with aerators, is increasing in acceptance as a waste disposal procedure.

#### CONCLUSION

Generally speaking, the disposal of whey for cheese factories in Southern Ontario has become an increasingly severe problem.

The solution is not necessarily one of making whey processing a profitable business, but rather to dispose of the whey in a socially acceptable manner with the least cost. In many of Ontario's smaller cheese factories, disposal of wastes including whey, as well as wash water, is a cost that has never been fully recognized.

The seriousness of the situation has recently been intensified because of loss of previously important outlets for whey:

- 1) The return of large volumes of whey to farms as hog feed has diminished in significance in Ontario to the point where it is only a minor factor. Whey as a supplementary hog feed has decreased in use because of technological changes in hog feeding and regulations that prohibit the hauling of whey in milk cans.
- 2) The other outlet for whey that is definitely of declining acceptability is the disposal of whey as waste. This is an inevitable outcome of the increasing awareness of the dangers of pollution. An unsatisfactory whey disposal system, that does not meet with the requirements of the Ontario Water Resources Commission and the Local Department of Health, is now generally recognized as undesirable from a public standpoint, and can lead to closure of non-complying plants.

There are various methods whereby whey can be utilized to advantage, and avoid the pollution problem.

The drying of whey, either by spray or by roller, to make either dried whey or lactose and lactalbumin, would appear to be among the more attractive methods for the disposal of large volumes of whey. Two specific conditions that must be met for satisfactory whey drying operations include:

- i) Adequate supplies of quality whey within reasonable trucking distance so that the equipment can run at or near capacity throughout the year. Because of high fixed costs, it is difficult to achieve profitability when running at less than capacity.
- ii) There must be sufficient demand at attractive prices for whey products, both roller-dried and spray-dried and lactose and lactalbumin so that processing operations can be sustained on a continuing and viable basis.<sup>31</sup>

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<sup>31</sup> According to industry sources, there is currently a growing international market for lactose and lactalbumin. The market for edible whey powder is reasonably firm, but needs to be expanded if the supply of whey powder is significantly increased.

There are several basic economic factors that have contributed to the problems of getting large quantities of whey processed by drying operations.

At the Cheese Factory, added capital expenditures are required in order to supply a quality whey. The low margins associated with cheese manufacturing do not facilitate added expenditures like stainless steel whey holding tanks, pasteurizers, and cooling equipment for whey. Yet, without this equipment the whey would not be sufficiently high quality to be processed for edible powder.<sup>32</sup>

The small volumes of cheese produced at some factories and the seasonality of whey production<sup>33</sup> are an added difficulty in the economic assembly of adequate supplies of raw material for a whey drying operation.

From Cheese Factory to Processor, a transportation problem exists. Transportation of whey is a major economic cost factor. Because the gross value of raw whey in most cases is less than 30¢ per cwt, the problem of transporting this bulky low-value product is readily apparent.

In Wisconsin, it was estimated that it was uneconomic to ship raw whey for distances greater than 50 miles. In Ontario, the transport rates for raw milk by bulk tank usually begins at 20¢ per cwt., and are frequently higher. Hence, a low-cost transportation procedure for whey must be developed for a viable operation. One method whereby transportation costs can be reduced would entail condensing of the whey to a concentrate having 50% solids, but this obviously introduces another cost into the picture.

At the Whey Processing Plant, the drying of whey involves substantial cash outlays. These may range from \$50,000 for a roller drying operation with a capacity of 77,000 lbs. of whey for a 22 hour period, to a cost of \$1,055,000 for a spray-drying operation has a daily capacity of one million lbs. of whey.

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<sup>32</sup> This point was vividly illustrated during an interview with a large-scale whey processor in Western Ontario who obtained some of his raw material from a distant cheese plant that has modern cooling and storage facilities while whey from a nearby cheese plant was unacceptable because of inadequate cooling and storage facilities.

<sup>33</sup> See Appendix 3 - "Seasonal Pattern of Ontario Cheese Production".



Careful handling of whey by skilled workers is a necessity. Roller-dried whey powder is normally hygroscopic. To produce a non-hygroscopic powder, a patented spray drying process may be required.

In summary, it might be concluded that drying whey is suitable primarily when large volumes can be economically assembled for processing. For smaller cheese factories that are situated some distances from processing facilities, and that cannot finance the new equipment (stainless steel holding tanks, pasteurizers, and cooling equipment), for a high quality liquid whey, several alternatives exist until such time as they are in a position to produce liquid whey in a form that is acceptable for the edible whey market.

a) Feeding Whey to Hogs.

Although currently unpopular in some parts of Ontario, this method appears to be quite acceptable in Wisconsin. To avoid trucking costs, whey can be pumped by plastic pipe for substantial distances at reasonable costs. This method might lend itself for use particularly in locations where a small cheese factory is situated in a remote area with insufficient volume of whey to support a drying operation, and where the soil near the cheese factory cannot absorb the whey. Liquid whey is considered to be a valuable supplement for hog feeding, when properly used.

b) Using Whey as Agricultural Fertilizer

The use of whey as fertilizer is not a common practice in Ontario. However, extensive tests in Wisconsin have shown whey to be a "soil builder" and a significant source of plant nutrients, particularly for corn and grasses. Three tons of whey contains about as much plant food as one ton of manure. Whey can easily be applied, using modern liquid manure equipment. Care should be taken that whey is applied to receptive crops, and that the rate of application is appropriate. As with other fertilizers, an excess amount can be harmful. One disadvantage of this method is seasonality. During the winter and spring months, it is difficult to get on the field to apply whey. Using whey as fertilizer in Ontario, may require further research.

c) Use as Sewage.

The disposal of whey as sewage is becoming more costly because whey is now recognized as a noxious pollutant.

It is still possible to dispose of whey as sewage but great care has to be taken to ensure that water supplies are not contaminated. On this subject, the Ontario Water Resources Commission has indicated "spray irrigation or land dumping ...is...acceptable where surface water pollution is not obviously apparent."

Spraying whey on land adjacent to the cheese factory may engender "bacteriophage" problems...and should be approached with caution because of risks of starter contamination. If great care is taken a suitable soil can absorb sufficient whey to provide an interim solution for some establishments. Lagoons, some with aerators, are increasing in use in the industry.

#### 4) Product Development Research

Much scope exists for further research work on whey products in Canada. A survey of Dairy Research found very few projects on whey currently in progress. A variety of new whey products have been developed in Europe recently (for example, vinegar and beverages), and their application to our particular circumstances in Ontario may warrant investigation.

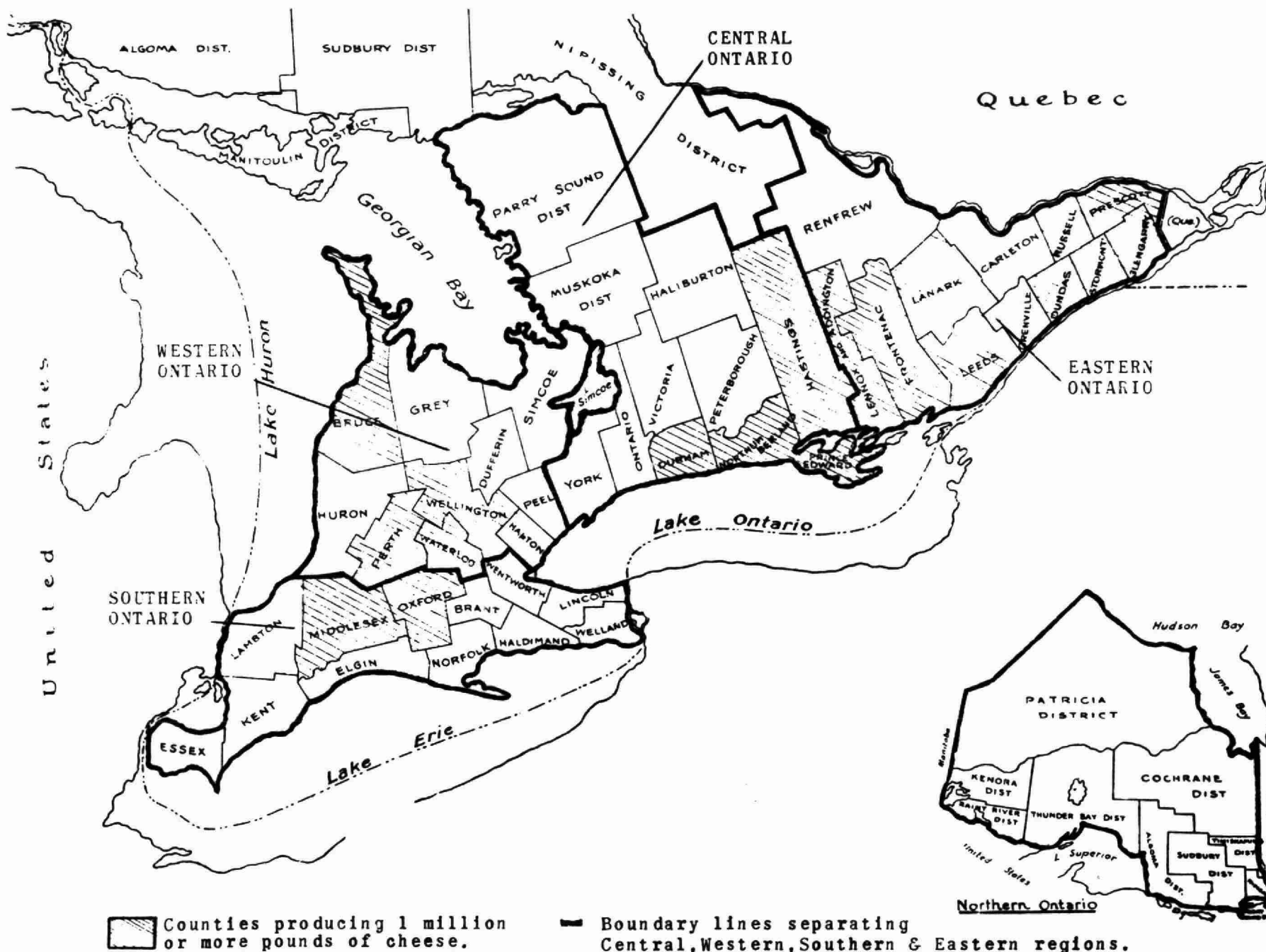
Considerable research has been done in the United States on the use of whey as an ingredient in the bakery industry, the frozen foods industry, the dehydrated foods industry, and related fields. An example of the growing commercial interest in whey processing in the United States is the fact that the U.S.A. had 90 processing plants for whey in 1964 and this number increased to 100 plants in 1965.

There is little doubt that further research is warranted, not only on the production aspects of whey, but also on their marketing potential, including consumer acceptance.

In addition to the domestic market for whey products, there may be a possibility of using whey in a food-aid programme for underdeveloped countries.

In instances where there have been procedures already established for publicly supported research, a whey product research programme may be useful in transforming the unused portion of this product into an item of economic value.

MAP 1  
CHEDDAR CHEESE PRODUCTION IN ONTARIO BY DISTRICT & COUNTY.





# DISTRIBUTION OF CHEESE FACTORIES & WHEY PROCESSING PLANTS

MAP II

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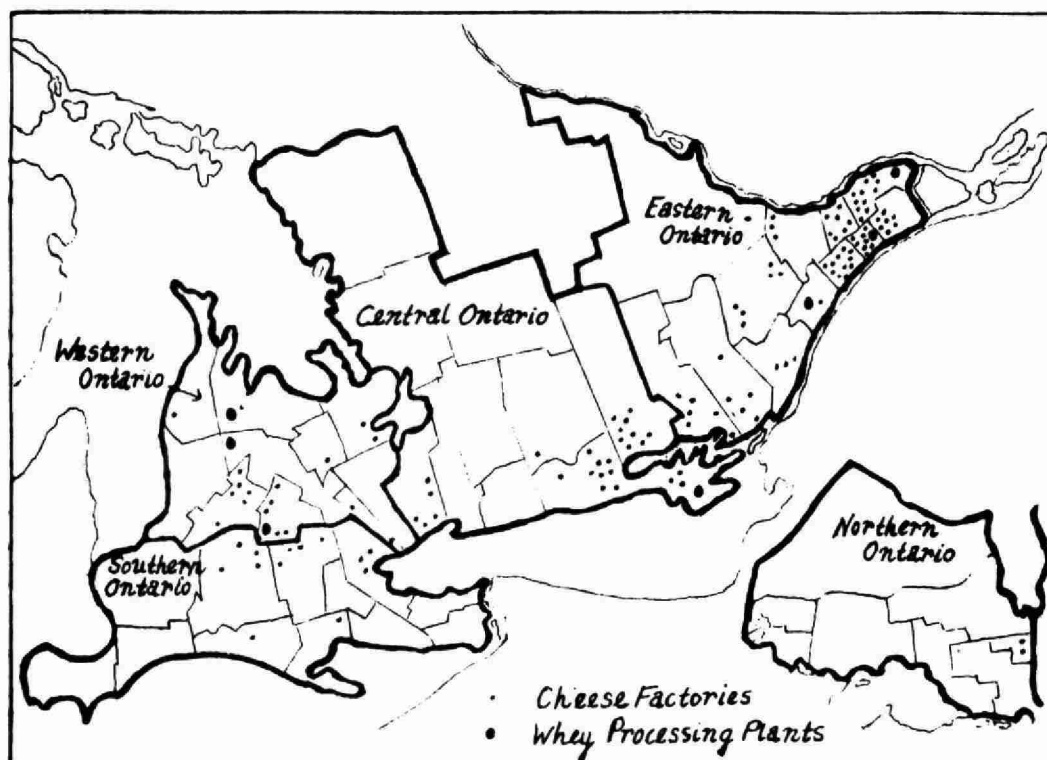


TABLE II    NUMBER OF FACTORIES PRODUCING CHEESE IN ONTARIO

Year      Number of  
Factories

1884 ..	567
1900 ..	1,167
1905 ..	1,198
1910 ..	1,102
1915 ..	995
1920 ..	889
1925 ..	785
1930 ..	735
1935 ..	707
1940 ..	639
1945 ..	570
1950 ..	408
1955 ..	245
1960 ..	160
1965 ..	146*

CHART I

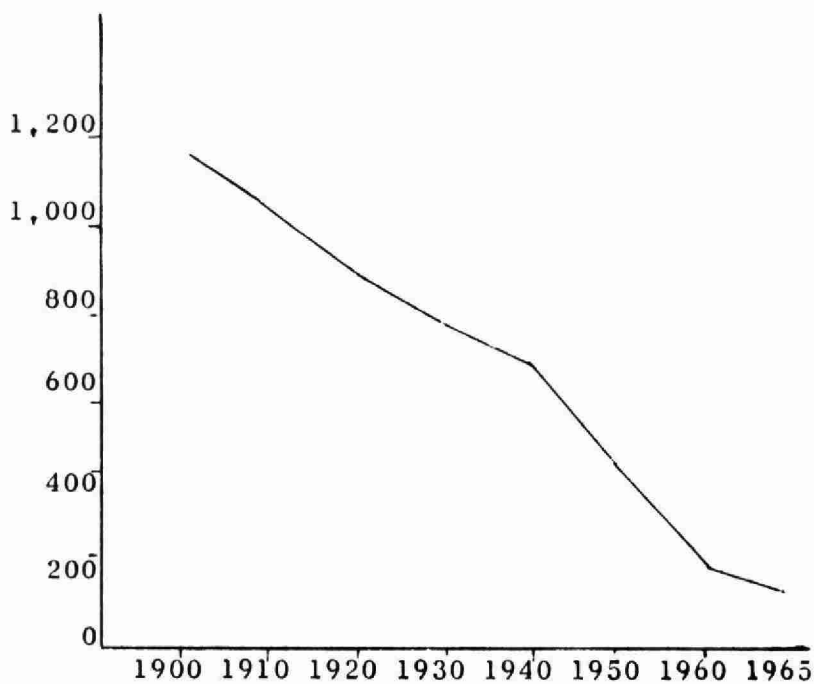
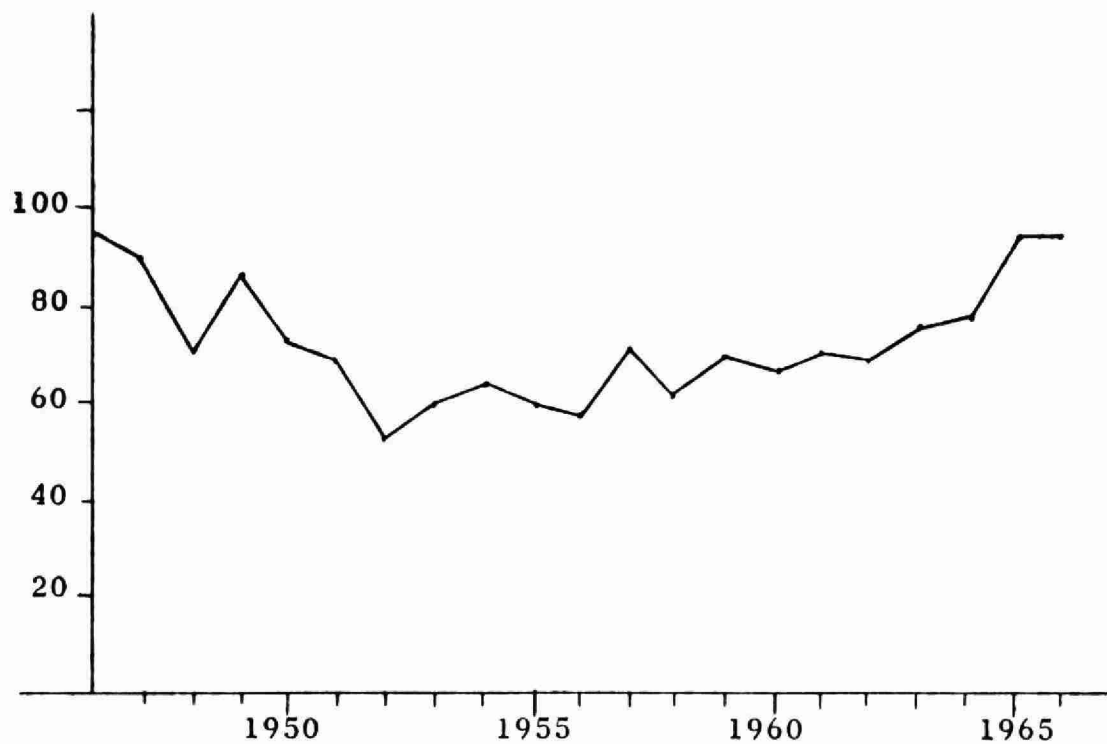


TABLE III     ANNUAL CHEESE PRODUCTION IN ONTARIO  
1946 - 1966

Year	lbs. '000	Year	lbs. '000	Year	lbs. '000
1946	95,282	1953	59,789	1960	66,939
1947	89,086	1954	63,377	1961	68,020
1948	68,157	1955	59,471	1962	67,376
1949	85,005	1956	57,470	1963	76,032
1950	70,270	1957	65,269	1964	77,899
1951	65,936	1958	62,732	1965	89,994
1952	51,294	1959	69,032	1966	89,293

CHART II



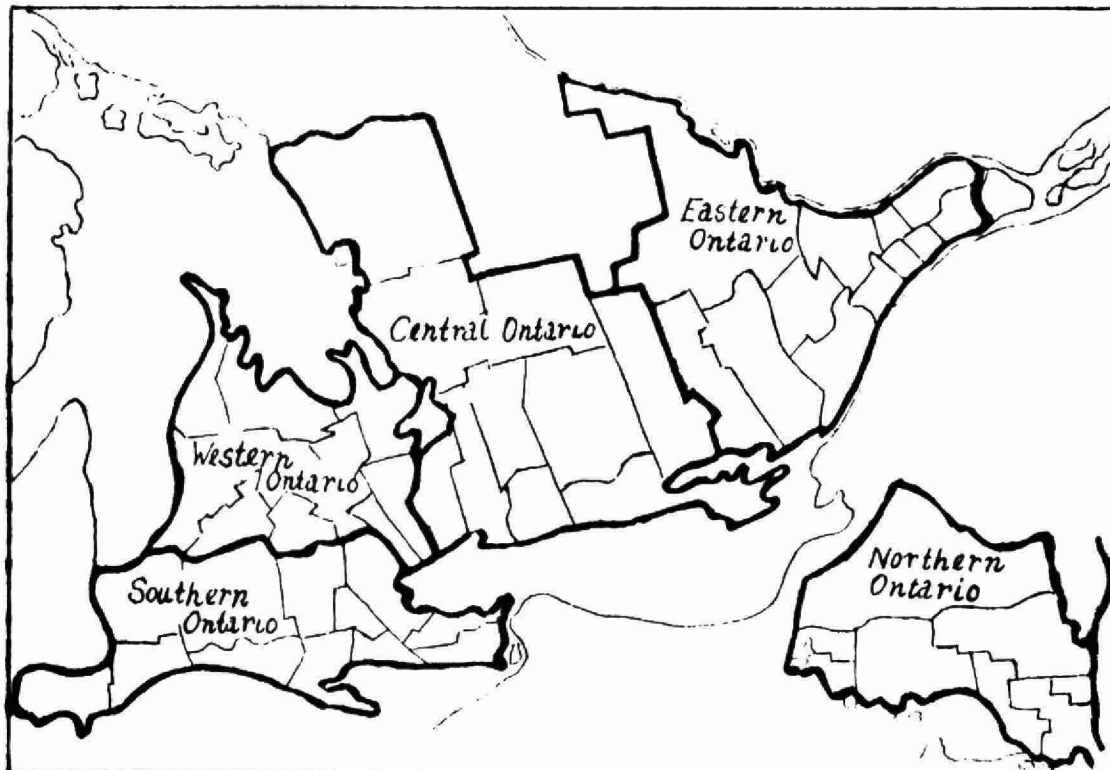
MAP III WHEY AND SEWAGE DISPOSAL IN ONTARIO - 1967

CENTRAL ONTARIO

Plants 27  
 Yearly Volume\* 157,025  
 Peak Volume 1,068  
 Investment\*\* \$56  
 Annual Cost\*\* \$11

EASTERN ONTARIO

Plants 68  
 Yearly Volume\* 771,259  
 Peak Volume 4,613  
 Investment\*\* \$202  
 Annual Cost\*\* \$ 88



WESTERN ONTARIO

Plants 14  
 Yearly Volume<sup>9</sup> 164,180  
 Peak Volume 804  
 Investment\*\*<sup>10</sup> \$54  
 Annual Cost\*\*<sup>10</sup> \$10

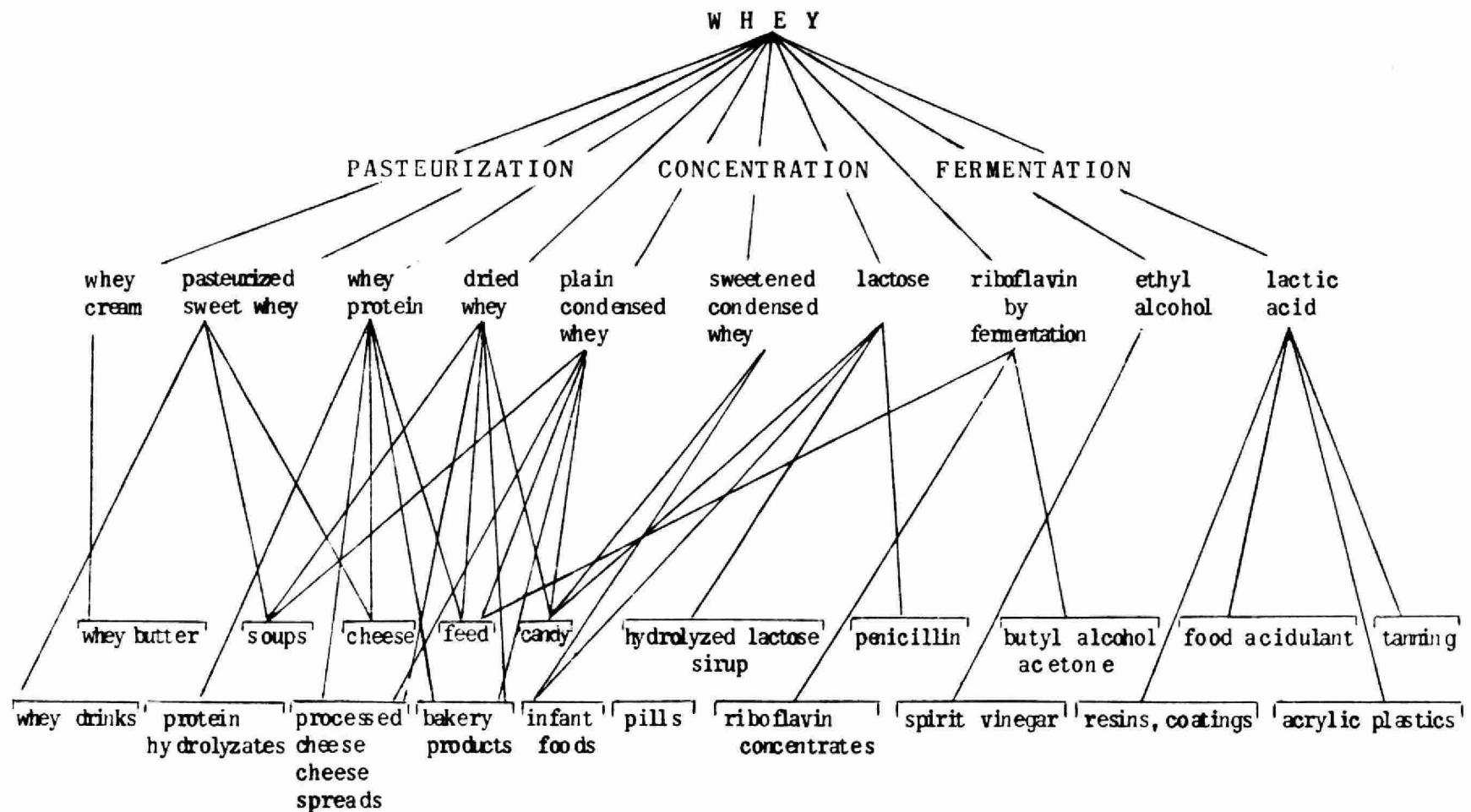
SOUTHERN ONTARIO

Plants 13  
 Yearly Volume<sup>9</sup> 73,224  
 Peak Volume 364  
 Investment\*\*<sup>10</sup> \$30  
 Annual Cost\*\*<sup>10</sup> \$8

NORTHERN ONTARIO

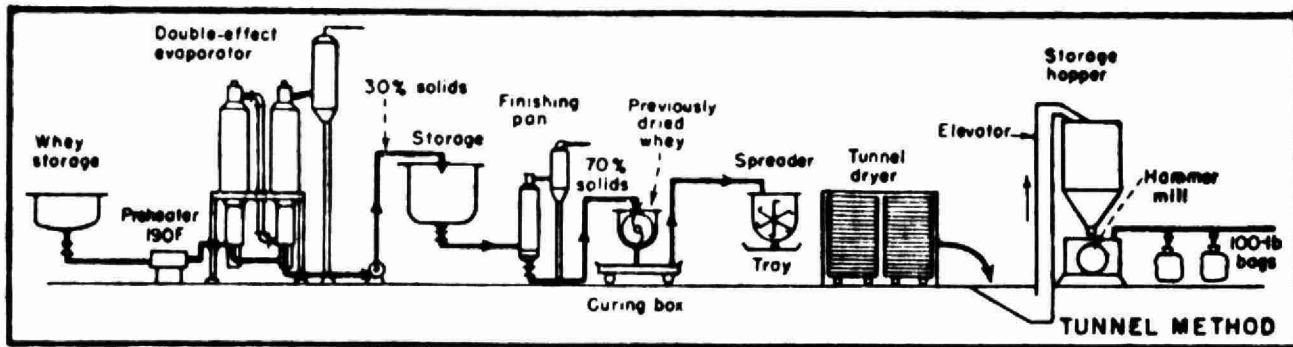
Plants 2  
 Yearly Volume<sup>9</sup> 17,651  
 Peak Volume 91  
 Investment\*\*<sup>10</sup> \$1

<sup>9</sup> \*Volume shown in thousands of pounds  
<sup>10</sup> \*\*Investment & Annual Expenditure shown in thousands of dollars

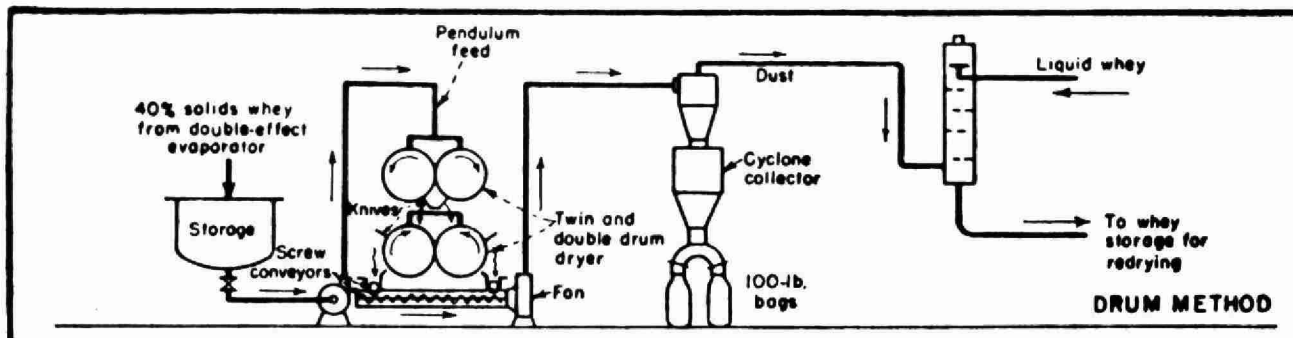


Source: E.O. Whittier & B.H. Webb. "By-products from Milk".  
Reproduced with permission from the author.

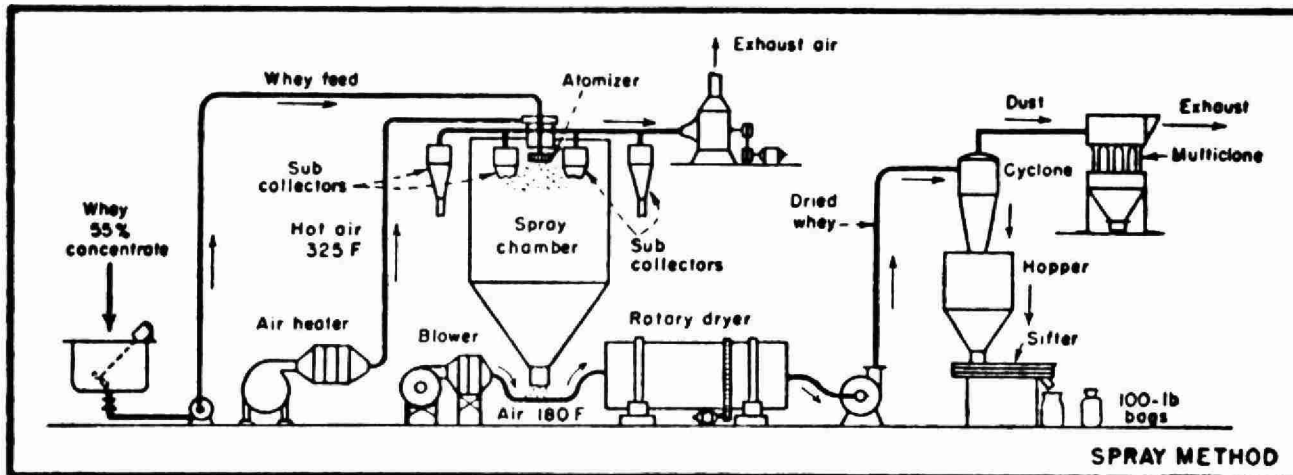
# PROCESSING OF RAW WHEY



By concentrating, then either tunnel drying . . .

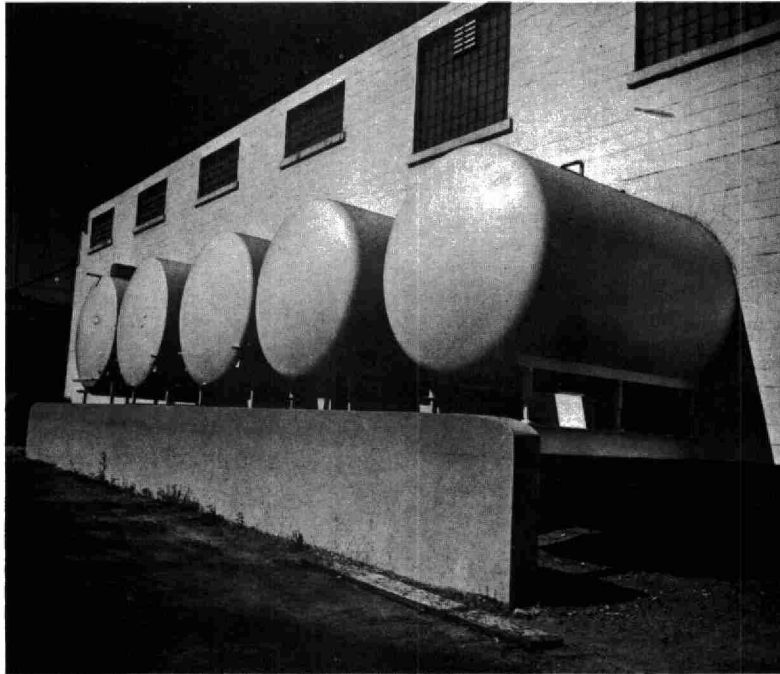


. . . drum drying . . .

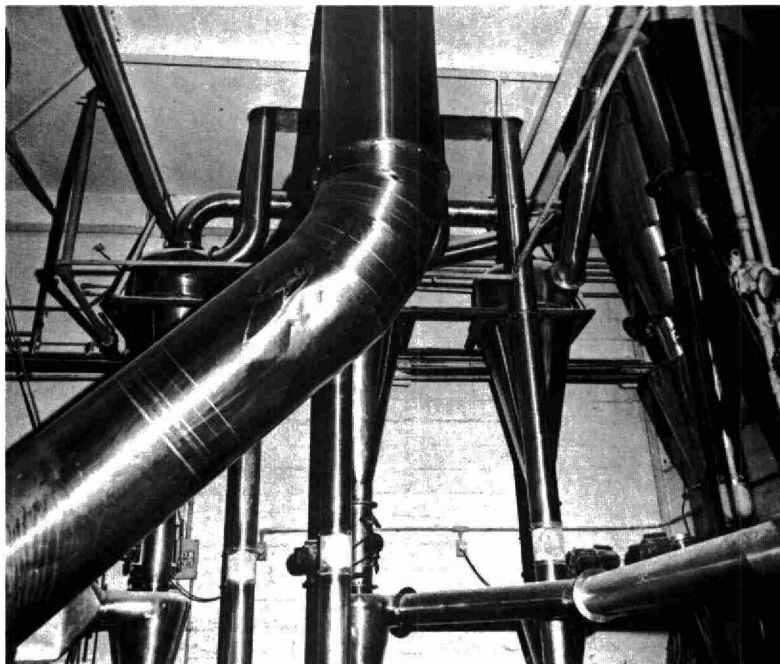


. . . or spray drying—

## STORAGE AND PROCESSING OF EDIBLE RAW WHEY

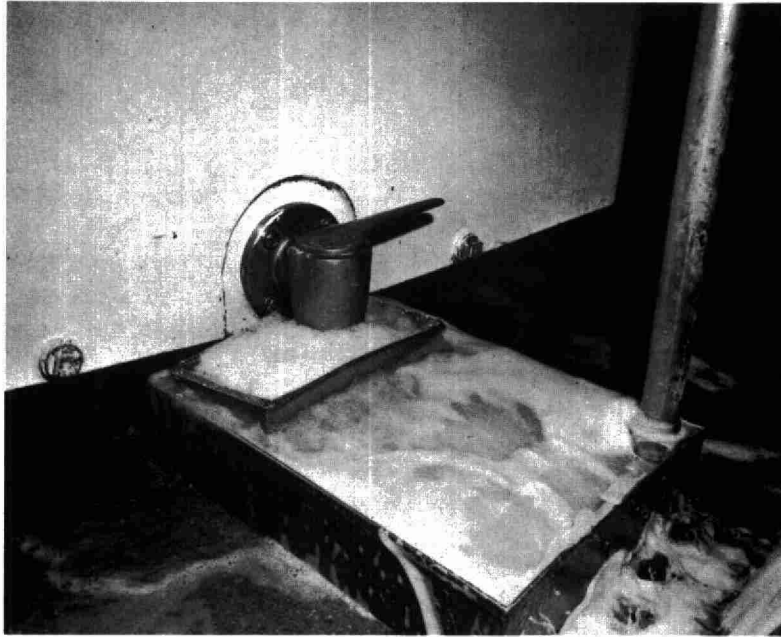


Stainless steel tanks hold whey destined for edible powder

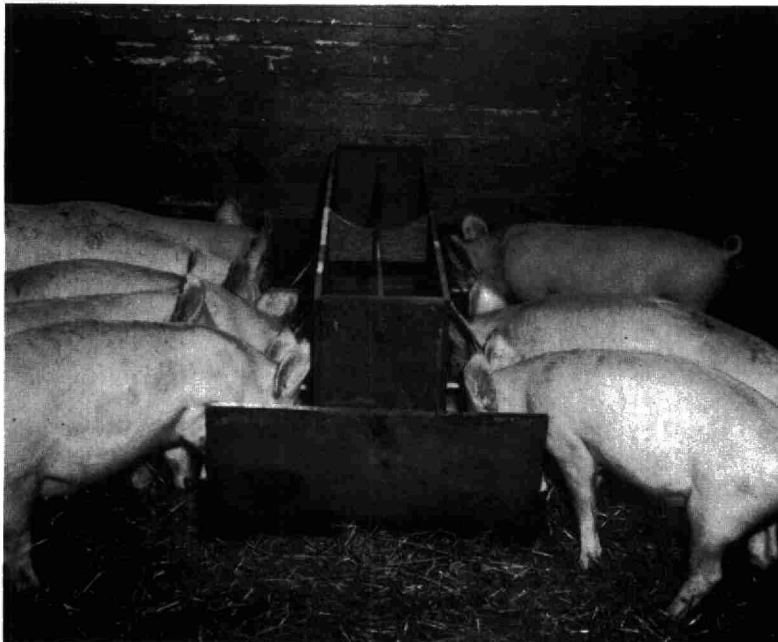


Processing of edible whey may involve complex equipment

RAW WHEY: ITS USE AS A HOG FEED



Large volumes of whey comes off the cheese vat



Some whey is currently used in the feeding of hogs

DISPOSAL OF RAW WHEY AND WASH WATER



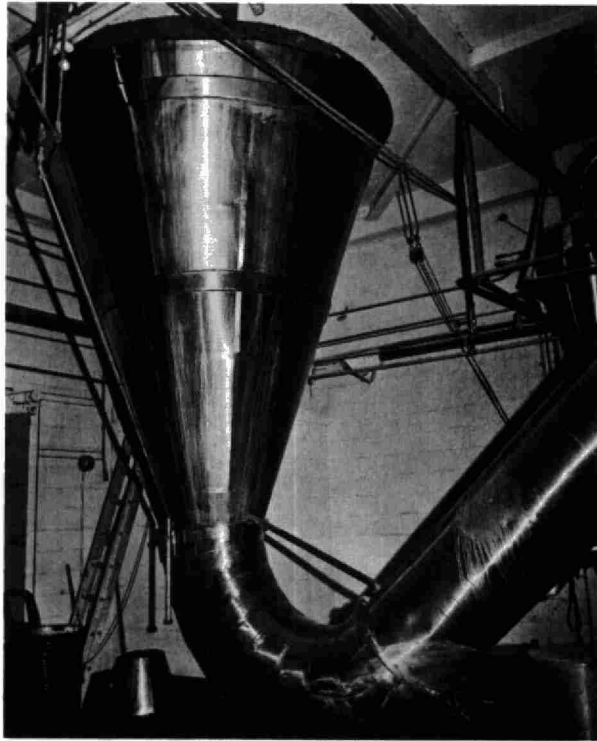
Lagoons are used to hold whey and wash-water for treatment



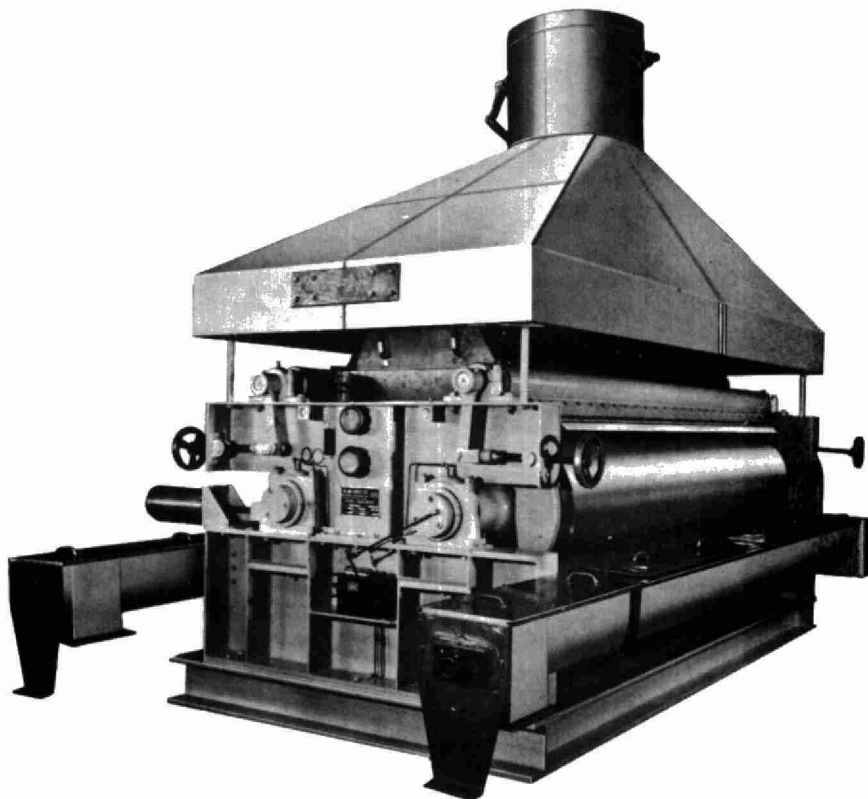
Some surplus whey and wash-water is sprayed on land



## METHODS OF DRYING WHEY



Spray drying equipment is both space-consuming and expensive



Roller-drying, by the drum method, may only involve one relatively compact unit



ONTARIO WATER RESOURCES COMMISSION

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TORONTO 5

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COMMISSION SECRETARY

May 15, 1967

Mr. W. R. Redelmeier, Senior Economist,  
Farm Economics, Co-Operatives & Statistics Branch,  
Ontario Department of Agriculture and Food,  
1901 Yonge Street,  
TORONTO 7, Ontario.

Dear Sir:

I have been asked by Mr. Caplice to reply to your letter of May 4, 1967, with regard to whey disposal at Ontario cheese factories. The following is a summary of the data in our files on Ontario cheese factories:

Total number of plants	-	128
Plants discharging wastes to municipal sanitary sewers	-	9
Plants discharging wastes to a natural watercourse	-	109
Plants discharging wastes to land	-	91
Plants with currently acceptable waste disposal practices	-	52
Plants with unacceptable waste disposal practices	-	37
Plants with seasonally acceptable waste disposal practices	-	30

... continued

Mr. W. R. Redelmeier, ... 2, May 15, 1967.

Plants with plans for control under active consideration	- 15
Plants with facilities for control under construction	- 3
Plants with no facilities planned or under construction	- 19
Plants with current status unknown or unidentified	- 7
Plants with operations temporarily suspended.	- 2

It is evident from this summary that only 40 percent of these plants have acceptable waste disposal practices and of the remainder, less than one-half have plans for improvements under construction or active consideration.

In almost all cases, whey disposal is the source of the unacceptable discharge. Very few plants recover whey by drying or for by-product manufacture because the capital cost of the equipment necessary is not justified by the marginal profit return in small scale operations.

Where no market is immediately available, most plants dispose of whey by spray irrigation or land dumping. The tendency is to regard this as acceptable where surface water pollution is not obviously apparent. Ground water pollution probably occurs where spray irrigation or land dumping is practised, but this is not regarded as serious as long as contamination of private wells and the occurrence of public nuisance effects do not result.

However, land disposal can only be utilized during the summer months and therefore, wastes must be stored during the winter. This is a source of seasonal pollution problems where storage capacity is absent or inadequate.

... continued

Mr. W. R. Redelmeier, ... 3, May 15, 1967.

More complete and extensive waste control is very difficult to achieve in this industry since it is often beyond the financial resources of the companies concerned. This would probably also apply to the chemical precipitation technique suggested in your letter.

There appears to be a trend in this industry toward consolidation into larger economic units and hopefully, this will lead to a more effective approach to pollution control.

Another approach worthy of consideration might be the application of financial assistance toward the establishment of centralized whey handling and processing plants. Evidently, whey drying and processing is only economically feasible on a large scale and therefore, beyond the financial resources of most of the plants in this industry which are small operations.

I hope that these comments are helpful in your study of whey disposal. If we can be of further assistance, please contact us.

Yours truly,

" H. A. CLARKE "

RAA/br

H. A. Clarke, M.A.Sc.,  
Assistant Director,  
Division of Industrial Wastes.

## APPENDIX 2

## LIST OF REFERENCES

- 1) Davis, J.G. Cheese, Vol. 1. Basic Technology. New York. American Elsevier Publishing Co. 1965.
- 2) Haslett, E.A. Cheddar Cheese Factories in Ontario. Ontario Department of Agriculture & Food. 1965.
- 3) Whittier, E.O. & Webb, B.H. By-Products from Milk. Reinhold Publishing Company, New York 18, U.S.A. 1950.
- 4) Report of the Minister of Agriculture. Province of Ontario. Queen's Printers (Various Years.)
- 5) Report of the Ontario Milk Industry, Inquiry Committee, Queen's Printers. January 1965.
- 6) Monthly Dairy Reports, Farm Economics, Co-operatives & Statistics Branch, Ontario Department of Agriculture & Food. (Various Issues).
- 7) Annual Production of Milk By-Products in Ontario. Published and Unpublished data from.
- 8) Food Processing August 1965. "Improve your products with whey solids".
- 9) Food Engineering. September 1960. "How Whey Solids can lift your profit two ways".
- 10) Ice Cream Field. April 1959. "What Whey is all about".
- 11) An Economic Analysis of Whey Utilization and Disposal in Wisconsin. University of Wisconsin College of Agriculture, Madison, Wisconsin. 1965.
- 12) Bourgeois Freres et cie., S.A. "A very interesting supplementary product, Lactavinegar". Ballaigues, Switzerland.
- 13) Hare, J. H. & Baker, B.E. "The precipitating of whey proteins using waste sulphite liquor". Canadian Journal of Technology. 1951.
- 14) Unpublished data from various sources as indicated on specific footnotes in the text.

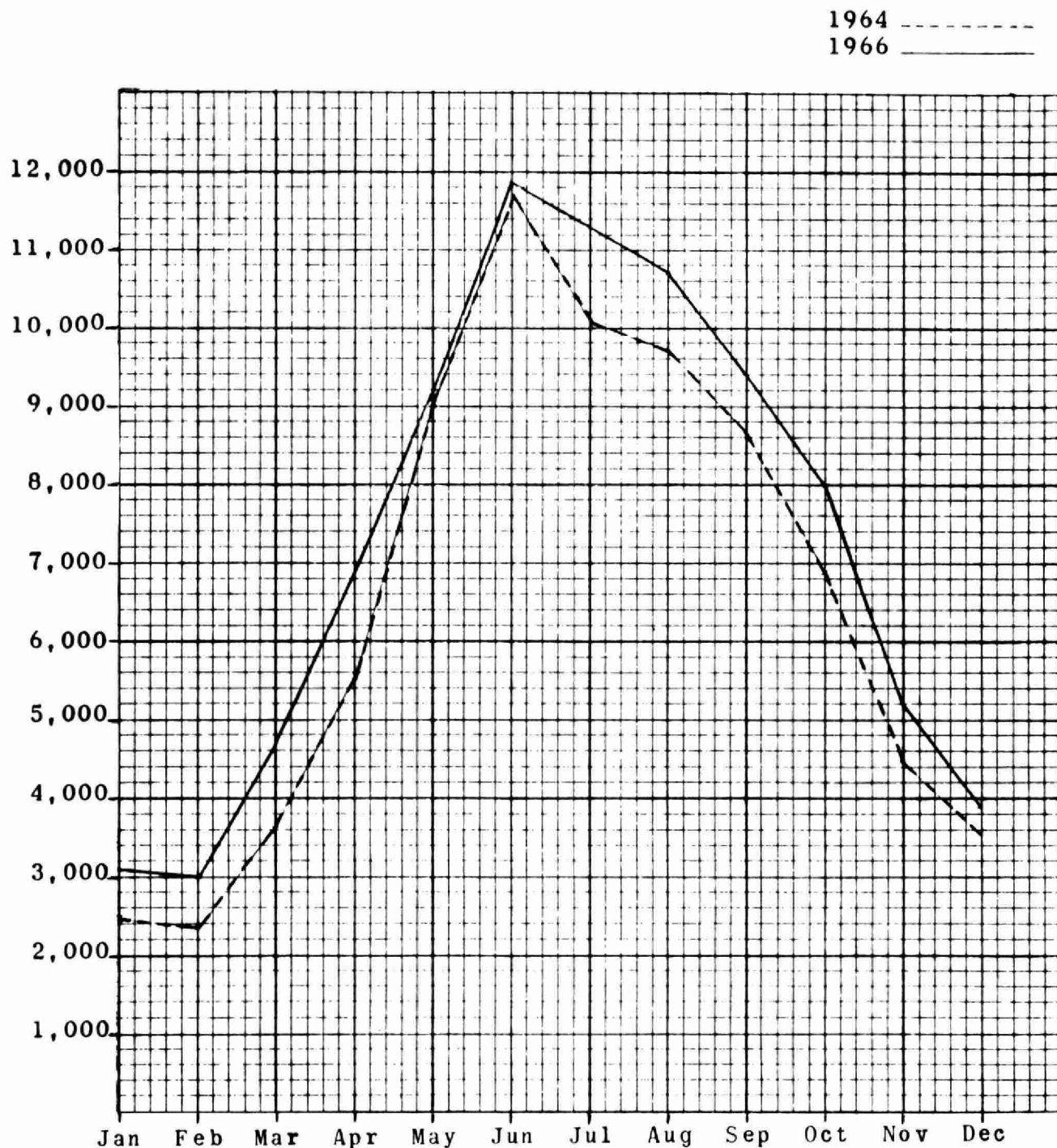
## PICTURE CREDITS

- 1) Ontario Department of Agriculture & Food (Information Branch)
- 11) Dairy Foods Service Bureau. (cover photograph)

### APPENDIX III

#### SEASONAL PATTERN OF ONTARIO CHEESE PRODUCTION: 1964 & 1966

(1,000 's of pounds)



Source: Dairy Factory Production, as published by  
Dominion Bureau of Statistics for 1964 & 1966

**TABLE VIII****SEASONAL PATTERN OF ONTARIO CHEESE PRODUCTION\***

(1,000's of pounds)

<u>Months</u>	<u>1964</u>	<u>1966</u>
January	2,428	3,029
February	2,194	2,447
March	3,441	4,180
April	5,574	6,861
May	9,116	9,185
June	11,687	11,933
July	10,152	10,694
August	9,788	10,694
September	8,648	9,579
October	6,943	7,995
November	4,412	5,049
December	3,516	3,961

<u>Months</u>	<u>1948</u>	<u>1949</u>
January	626	468
February	610	339
March	1,218	1,085
April	2,921	4,437
May	8,311	11,728
June	14,242	15,381
July	12,686	13,098
August	10,712	11,293
September	8,407	10,906
October	5,249	9,316
November	2,229	4,969
December	946	1,985

The seasonal pattern shows an annual peak production in May, June, July and August. The sharpness of this seasonality, although diminished from 1948 and 1949, is still quite apparent.

\* Source: Dairy Factory Production as published by Dominion Bureau of Statistics for 1964 & 1966.



"PHOSPHATE REMOVAL BY ACID HYDROLYSIS  
AND CHEMICAL PRECIPITATION"

BY

CECIL LUE-HING, ASSOCIATE  
H. D. TOMLINSON, VICE PRESIDENT  
D. W. RYCKMAN, PRESIDENT  
RYCKMAN, EDGERLEY, TOMLINSON & ASSOCIATES, INC.  
ST. LOUIS, MISSOURI

Current technology and methodology for the removal of phosphates from waste-waters are presently being directed almost exclusively at domestic sewages and/or mixed municipal wastes having a total phosphate content of less than 100 mg/l. The methods currently being proposed were suggested by Rudolfs (1) as early as 1947, and confirmed by Sawyer (2) in 1952, and by Rohlich (3) in 1954. These methods consist essentially of the direct addition of hydrated lime alone  $\text{Ca}(\text{OH})_2$ , to domestic or municipal waste-waters, or the addition of lime in combination with iron or aluminum ions which form settleable precipitates with the phosphates present, thus causing their removal.

Although the current literature is replete with case histories of successful applications of these methods, there are indeed very few of these case histories covering full scale waste treatment plant operations. The great majority of these reports are for laboratory scale operations, a few are for pilot plant operations and a distinct minority for full scale operations.



The distinctive features of current methods for phosphate removal may be summarized as follows:

- 1) Phosphate removal is accomplished by alkaline removal with lime within the pH range of pH 8.0 to pH 11.0.
- 2) Phosphate removal is accomplished also by adsorption or precipitation with metallic hydroxides.

In addition, the phosphate compounds being removed are primarily "inorganic phosphates" and their concentrations seldom exceed 100 mg/l.

A recent review of current phosphate removal methods by Weinberger (4) presents an excellent outline of the various processes together with their reported efficiencies and their respective projected costs for full scale operations.

Unfortunately, the methods currently being proposed for phosphate removal fail to consider the problem of organic phosphates, especially those associated with industrial waste-waters. The waste-waters from many industrial operations are rich in organic phosphates, and proper treatment of these wastes cannot be accomplished without effective phosphate removal. If present methods were employed to treat these industrial waste-waters, then the resulting high pH of the effluent would eliminate the use of biological treatment which more than likely would be desirable to reduce the concentrations of dissolved organic material to within acceptable limits. Furthermore, some phosphate rich industrial waste-waters by their very nature are simultaneously inherently toxic, and possess high organic content, thus making the utilization of acclimated biological oxidation an attractive possibility, for any proposed waste-water treatment system or scheme. Lue-Hing (5), has recently reported on such a system.

The method of phosphate removal by acid catalyzed hydrolysis and chemical precipitation being presented here, was developed primarily for solving a specific problem involving toxic industrial waste-waters rich in organic phosphates (phosphorus esters). However, the method will remove inorganic phosphates from domestic sewages and mixed municipal waste-waters with equal facility and with no loss in efficiency.

## Sources and Types of Phosphates

The several major sources which contribute to the phosphorus content of natural waters are:

- (a) domestic
- (b) industrial
- (c) agricultural
- (d) natural

The fact that phosphate containing waste-waters generated by domestic and industrial activities can readily be collected and brought to a central point for treatment, establishes their amenability to more effective and economical control of their phosphate content as compared to waste-waters arising from natural and agricultural sources. Therefore, from the standpoint of phosphate removal in wastewater treatment, the major sources of immediate concern are domestic and industrial.

It is now well established that cleaning compounds such as household synthetic detergents, soap detergents, and other similar cleaning materials are composed of builders which contain inorganic condensed phosphates. It has been shown also by Sawyer (6) that some synthetic detergents contain as much as 50 per cent. dry weight of these inorganic condensed phosphates which include sodium tripolyphosphate (STP) and tetrasodium pyrophosphate (TSPP).

Organic phosphorus compounds, - organophosphates -, have been shown to be important both from an economic standpoint and also as a medium for satisfying the domestic and industrial needs of our present society. Chadwick (7) has indicated recently that about one-third of the organophosphates produced in the U. S. is utilized in the manufacture of oil additives; one-third in phosphate ester plasticizers, fuel additives and functional fluids; and one-third in insecticides, insecticide intermediates and other miscellaneous uses.

According to O'Brien (8), there are four basic phosphorus starting materials from which almost all the currently used organophosphates can be prepared. These materials are:

- 1)  $\text{PCl}_3$  and
- 2)  $\text{P}(\text{O})\text{Cl}_3$ , from which compounds of phosphates or phosphorothiolates can be prepared
- 3)  $\text{P}(\text{S})\text{Cl}_3$ , from which compounds of phosphorothionates can be prepared
- 4)  $\text{P}_2\text{S}_5$ , from which compounds of phosphorodithioates can be prepared.

## Organic Phosphorus Esters - Organophosphates

The four (4) basic phosphorus starting compounds already mentioned, can be used to produce several different groups of - organophosphate - products, including organic phosphorus esters. Many of these organophosphate compounds are biologically toxic; some are marketed under proprietary labels, while others are marketed under their common chemical names. The group of compounds which are related to the phosphate removal process being reported are the toxic organic phosphorus esters - organophosphates.

## Hydrolysis - Hydrolytic Degradation of Organophosphates

Through the remainder of this discussion, the terms Hydrolysis and Hydrolytic Degradation will be used interchangeably, so also will the terms toxic organophosphates and organophosphates.

The great majority of the organophosphate compounds in use today are esters of phosphoric or other related acids, or of their anhydrides, halides, or amides. This unique feature makes them all potentially hydrolyzable, or susceptible to some extent to hydrolytic degradation. In terms of hydrolytic degradation, it is believed that the most labile chemical bonds are the anhydride or halide, the next being the alkoxy, and then the amide.

The rate of hydrolysis of organophosphates is found to be governed by many factors including the following:

- 1) pH variations
- 2) temperature variations
- 3) type and concentration of catalysts
- 4) structure of compounds
- 5) type of solvent
- 6) colloidal gels
- 7) complexing cations
- 8) enzymes.

Perhaps it should be emphasized at this point that any one of the above 8 factors could govern the rate of hydrolytic degradation, provided other factors and environmental conditions are so arranged to permit this. It should be emphasized also that the economics of present wastewater treatment practices quite often will not permit the use or application of certain environmental factors, even when these factors are known to be effective. Examples in this case would be the use of elevated temperatures, or organic solvents to promote the rate of hydrolytic degradation of the organophosphates of interest. This, in spite

of the fact that the variation of the rate constant K, can be expressed in terms of the Arrhenius equation

$$K = A e^{E/RT}$$

where the temperature independent-term, A, is called the frequency factor; E the activation energy; R the gas constant and T the absolute temperature.

It is obvious, therefore, that waste-water treatment processes should be straight forward in design and readily applicable to full scale operations, to permit their use over a wide range of practical situations.

### Acid Catalysis

It has been known for a long time that certain phosphorus compounds - the esters of phosphoric and other related acids - especially some of the toxic esters, will undergo hydrolysis or hydrolytic degradation in alkaline solutions, some in neutral solutions and some in acid solutions. Results of the work of many investigators, including Heath (9) and Plimmer (10) have confirmed this fact.

It has been shown by many investigators, including Butcher (11), that the hydrolysis of many organophosphate esters of the form  $(RO)P(O)(OH)_2$  demonstrate a very interesting pH dependence. An example of this phenomenon is given in Figure 1. Figure 1 shows that the reaction rate constant K increases to a maximum at pH 4.0 as this pH value is approached from either side. It has been proposed that the compounds of interest are brought to a state of maximum molecular instability at or near this pH value. This situation probably indicates that the phosphate moiety of the molecules under these conditions are most susceptible to complexation, for example, by multivalent metallic ions such as calcium -  $Ca^{++}$ .

Results of studies by other workers including Chanley (12) on the rupture of phosphate linkages, have also demonstrated the pH dependence of the rate of hydrolysis of some of these compounds. An example of this is shown in Figure 2. Again, it is seen from Figure 2 that the reaction rate constant is maximum at pH values near pH 4.0.

### Process for Phosphate Removal

In reviewing the eight (8) factors which are known to affect the rate of hydrolytic degradation of organo-

phosphates, it becomes immediately apparent that the parameter most adaptable to full scale operational monitoring and control is the pH. Inasmuch as acid, neutral and alkaline pH conditions could be applicable depending on other factors, such as chemical characteristics of the waste-waters, the decision had to be made regarding the pH most suitable to permit the type and extent of hydrolytic degradation required. It should be noted also that since the phosphate removal process constitutes only one step in the total waste-water treatment system, this process should be compatible with the total system.

It was decided, therefore, that the phosphate process should satisfy the following basic conditions:

- 1) Permit removal of phosphate in excess of 90% over a wide range of conditions.
- 2) Permit this removal consistently.
- 3) The process should be compatible with subsequent unit treatment processes for BOD and COD removal, with special attention being given to the possible use of biological oxidation for waste-waters with high organic content.

The acid chemical process being proposed, accomplishes removal of phosphates in the following steps:

- 1) The phosphate rich waste-waters are adjusted to a predetermined optimum pH for maximum hydrolytic degradation at ambient temperatures.
- 2) The waste-waters are then reacted with hydrated lime to form insoluble precipitates of calcium phosphate.
- 3) The precipitates of calcium phosphate are flocculated and removed as sludge in the primary sedimentation system.
- 4) The clarified effluent relatively free of phosphates is released to the other treatment units for further treatment as required.

#### Results of Phosphate Removal

As previously mentioned, the method of "phosphate removal by acid catalyzed hydrolytic degradation and chemical precipitation" has proven equally effective for industrial waste-waters rich in organic phosphates, domestic sewages, and mixed municipal waste-waters. Figure 3 shows some results obtained on one sample of industrial waste-water. This figure shows that influent phosphate concentrations of 2,000 mg/l can be reduced to practically zero. This waste, for example, could be made phosphate deficient for subsequent



biological oxidation. Figure 4 shows a comparison of results for domestic and industrial waste-waters. These curves again indicate that in either case, both wastes could be made phosphate deficient for subsequent biological oxidation.

It should be stated that 2,000 mg/l of phosphates as  $\text{PO}_4$  do not represent the limit of phosphate concentrations which can be removed by the proposed acid process. It is believed at this stage that the upper limits of phosphate concentrations are practically infinite.

### Calcium Build-Up in Biological Sludges

In order to further reduce the organic content of the waste-waters studied, the chemically treated waste-waters were fed to acclimated biological systems. It was found during these studies that calcium phosphate precipitates (crystals) could build up in the activated sludge system, depending on such factors as:

- 1) The efficiency of the primary sedimentation system following chemical treatment.
- 2) The effluent pH following chemical treatment, and
- 3) Other inherent chemical characteristics of the waste-waters being treated.

Figure 5, Figure 6 and Figure 7 show examples of calcium phosphate and calcium sulphate crystals in the activated sludge cultures. The biological significance of this calcium build-up has not yet been determined.

### Costs

Since the phosphate content of the industrial waste-waters studied were much higher than those of the domestic sewages, cost figures were developed for lime usage on the basis of weight of lime required per unit weight of  $\text{PO}_4$  removed. Results show that the amount of lime required to treat domestic sewages per unit weight of  $\text{PO}_4$  removal was much greater than for the industrial wastes. The average ratio for domestic sewage: industrial wastes, was found to be approximately 4:1. Some results on lime requirements are shown in Table 1.

### Discussion and Summary

Many methods are now currently being offered for the removal of phosphates from waste-waters. These methods, however, are all designed to treat waste-waters with relatively low inorganic phosphate content, particularly

domestic sewages with  $\text{PO}_4$  content of 100 mg/l or less. These methods are not capable of providing effective treatment for industrial waste-waters which contain organic phosphates of much higher concentrations, which sometimes may be 50 times the concentrations found in domestic sewages.

The proposed method of phosphate removal by "acid catalyzed hydrolytic degradation and chemical precipitation" have demonstrated its effectiveness both for industrial waste-waters rich in organic phosphates and domestic sewages. Projected costs of the acid process appears more favorable especially in terms of lime requirements, since it requires less than 25% of the lime used in other processes per unit weight of  $\text{PO}_4$  removed.

Alkaline removal of phosphate produces a calcium phosphate precipitate commonly referred to as hydroxylapatite -  $\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$  - which is notoriously resistant to flocculation and sedimentation. Preliminary results so far have indicated that all chemical phosphate removal processes presently in use, both alkaline and acid, could produce excessive build-up of calcium phosphate precipitates in subsequent biological oxidation systems. Since the present trend in phosphate removal seems to have acquired national scope, basic research on the effects of  $\text{PO}_4$  build-up in biological treatment systems seems to be a desirable investment at this time. Such research may very well produce answers which could avoid possible future complications in biological waste treatment systems utilizing chemical phosphate removal processes in the primary treatment system. In other words, the compatibility of proposed phosphate removal processes with existing biological treatment systems need further confirmation.

## Conclusions

1. Phosphate removal by "acid catalyzed hydrolytic degradation and lime precipitation" has proven to be an effective method for removing high concentrations of organic phosphates from waste-waters. The theoretical limits of phosphate concentrations which may be removed by this process appear to be infinite.
2. The method has proven to be more effective than other methods over a wider range of phosphate concentrations and phosphate complexes, including the following:
  - (a) toxic and non-toxic organic phosphates
  - (b) domestic and other detergent related phosphates.

TABLE 1  
LIME REQUIREMENTS FOR  
DOMESTIC SEWAGE AND INDUSTRIAL WASTE

<u>Waste Sample</u>	<u>Total PO<sub>4</sub> -Influent- mg/l</u>	<u>Total PO<sub>4</sub> Removed -Percent-</u>	<u>Lime Requirements</u>	
			<u>Lime Used mg/l</u>	<u>Ratio: Lime Used PO<sub>4</sub> Removed</u>
Domestic Sewage	100	85	200	2.0:1.0
Industrial Waste	4,000	95	1,750	0.44:1.0



3. The near neutral pH range (pH 7-8) of the chemically treated effluent permits feeding directly to aerobic biological oxidation systems. This is particularly attractive if the waste-waters of interest have high concentrations of organic material for the following reasons:
  - (a) a pH of 8.0 is not objectionable for aerobic biological oxidation
  - (b) a pH of 8.0 contains enough alkalinity to off-set the effects of the organic acids produced during aerobic bio-oxidation of waste-waters with high organic content.
4. The projected costs of the acid process are lower than for other processes since the lime required is less than 25% of that used by other processes in terms of unit weight of  $\text{PO}_4$  removed.
5. Under acid pH conditions, the predominant calcium phosphate precipitate is tribasic calcium phosphate -  $\text{Ca}_3(\text{PO}_4)_2$  - while under alkaline pH conditions, the predominant form is hydroxylapatite  $\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$ .
6. Research is urgently needed to determine the effects of excessive build-up of calcium phosphate, and other metallo-phosphate complexes, e.g., aluminum and iron phosphates in aerobic and anaerobic biological treatment systems.
7. The authors have strong reservations against any statement which implies that technology on phosphate removal is available to produce wholly satisfactory results. Our basic reservations are as follows:
  - (a) The kinetics of  $\text{PO}_4$  removal by  $\text{Ca}(\text{OH})_2$  in waste-waters are not sufficiently well understood to permit immediate implementation on a national scale.
  - (b) We are not fully convinced that excessive build-up of metallo-phosphates and other precipitated phosphates in aerobic and anaerobic biological

treatment systems is completely compatible with, and harmless to, these systems.

- (c) The pH conditions associated with anaerobic sludge digestion could produce partial conversion of precipitated phosphates to various forms of free orthophosphoric acids either to be later discharged as effluent, or returned to the influent end of a waste treatment plant, thus defeating the purpose of phosphate removal!

FIGURE I  
RELATIONSHIP OF pH TO Kh

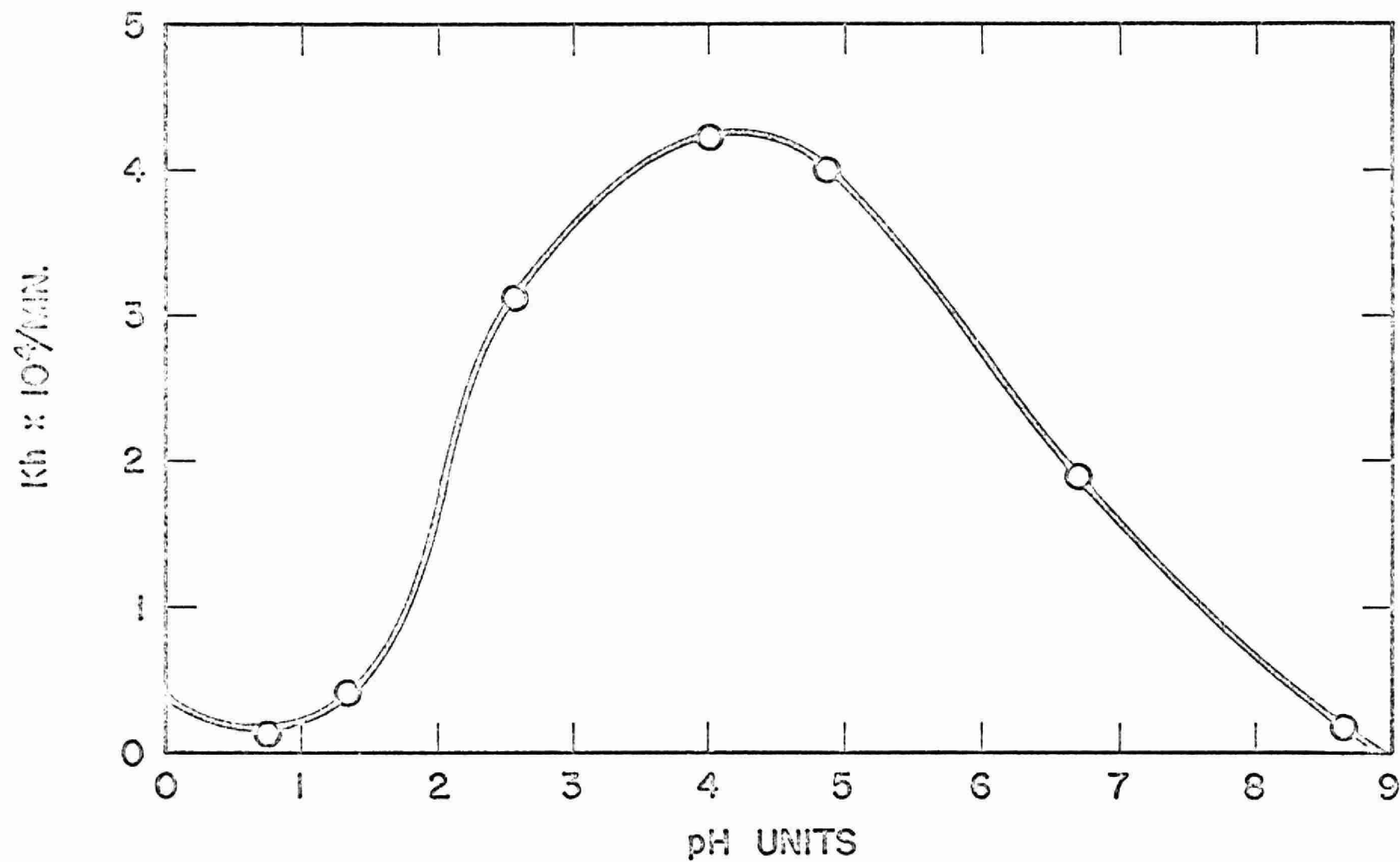


FIGURE 2  
HYDROLYSIS OF C-O-P LINKAGES

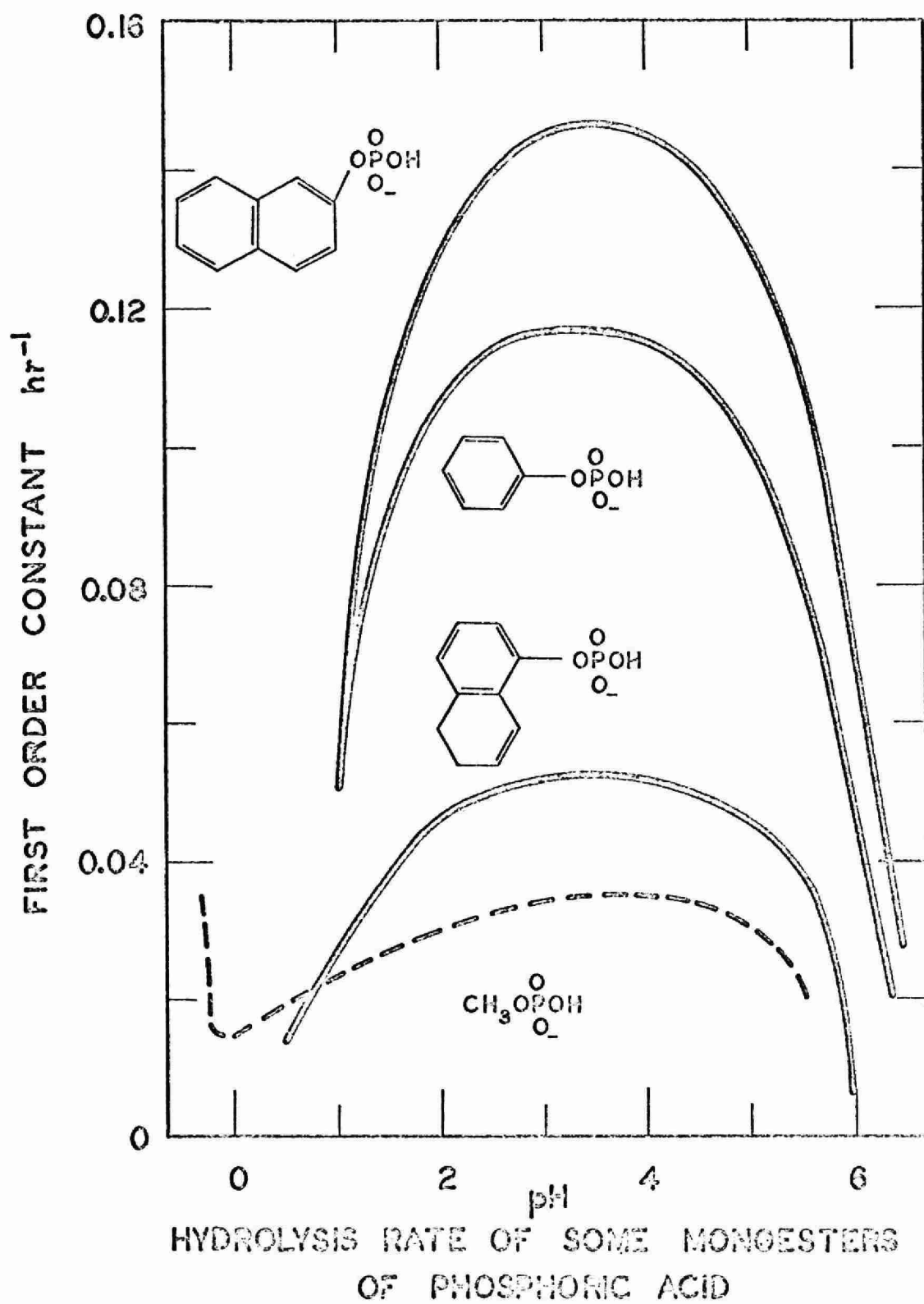


FIGURE 3  
RELATIONSHIP OF pH TO  $\text{PO}_4$  REMOVAL

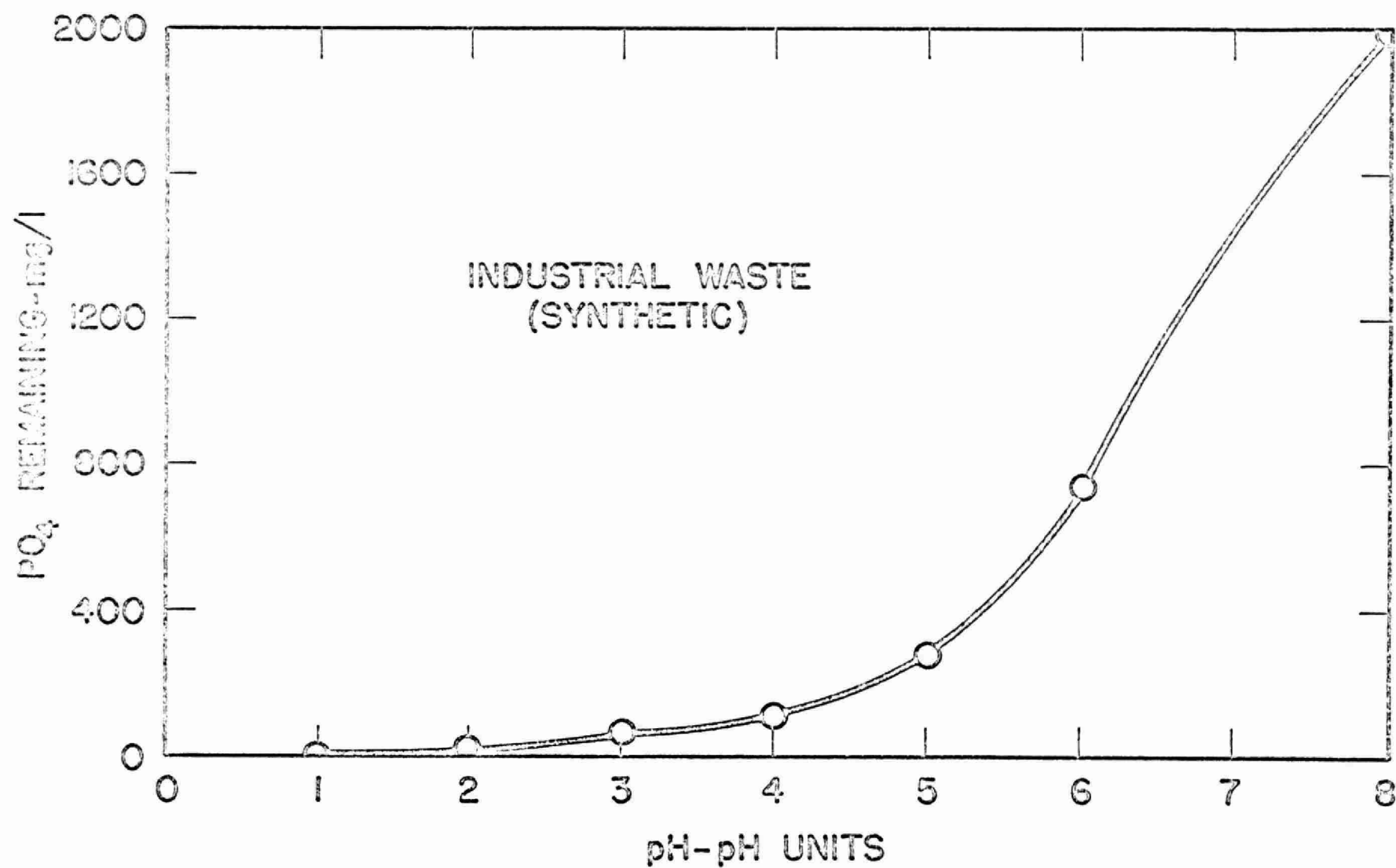
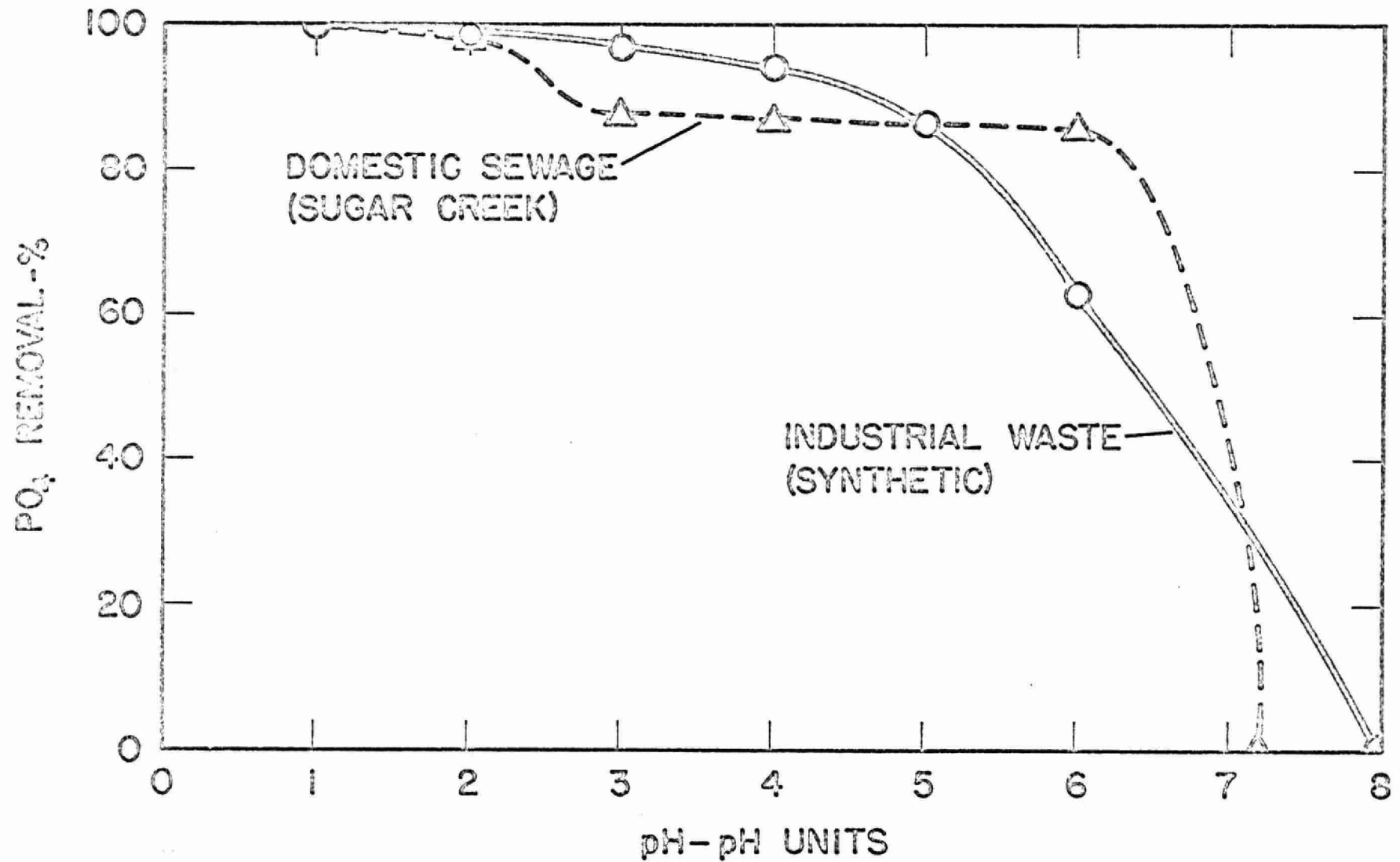


FIGURE 4

EFFECTS OF INITIAL pH ON  $\text{PO}_4$  REMOVAL



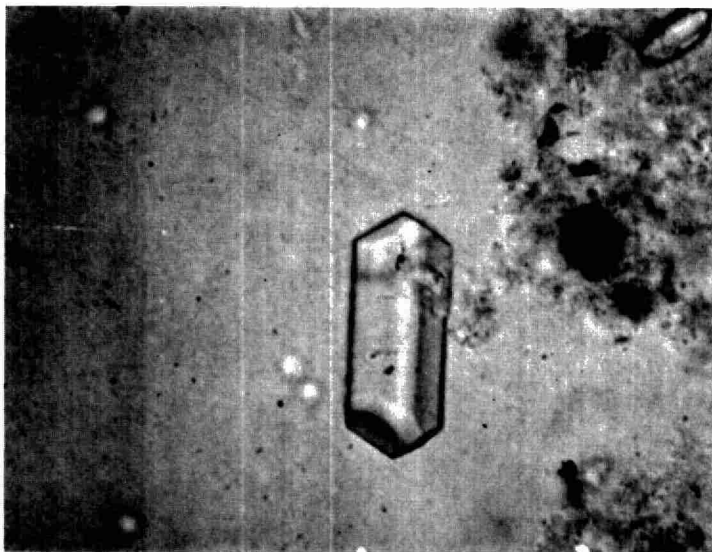


FIGURE 5 - Calcium Phosphate Crystal in Activated  
Sludge Culture - x 450



FIGURE 6 - Calcium Sulfate Crystals in Activated  
Sludge Culture - x 450

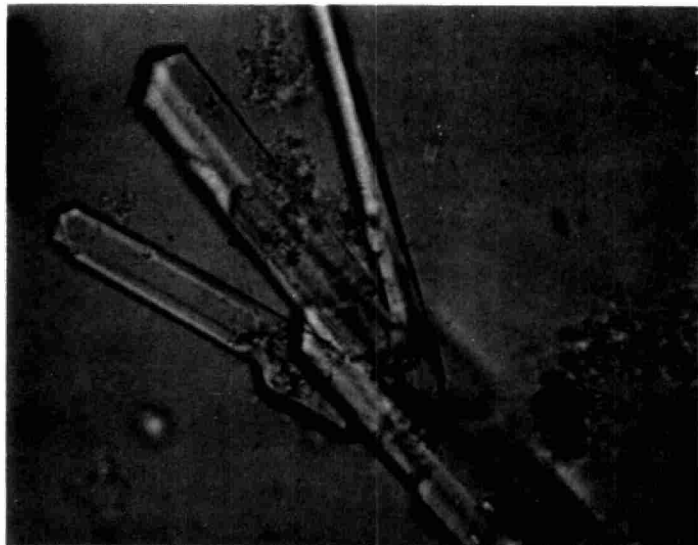


FIGURE 7 - CALCIUM PHOSPHATE CRYSTALS IN  
ACTIVATED SLUDGE - x 450



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"BREAKING THE BARRIERS OF TIME - A PROFILE  
OF AIR TRAVEL IN THE FUTURE"

BY

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It is a fact that scientific technology has advanced more rapidly in the past 50 years than in the previous 5,000. Consequently, men in the air travel industry realize that they must look at least two decades ahead to keep abreast of the times. Faced with the atom's almost limitless energy and the computer's almost limitless intellect, they must learn to predict and anticipate an era of almost limitless change.

Although the business of prophecy can be a hazardous occupation, failures of vision in aviation can be even more dangerous.

In 1910, for example, the famous American astronomer and scientist William H. Pickering could not imagine the concepts of giant flying machines crossing the Atlantic with innumerable passengers or being used in time of war to drop dynamite on the enemy. U.S. scientists just after World War II dismissed the notion of an accurate intercontinental ballistic missile. In addition, the prospect of space travel was termed "utter bilge" by

Britain's Astronomer Royal as late as 1956.

In the 1950's, aviation authorities maintained that commercial jet transports could not compete with conventional piston aircraft in terms of cost. Now the same "authorities" state that supersonic jet transports will not be able to compete with well-developed subsonic jet planes, such as the DC-8 and DC-9. "They said it couldn't be done", is a phrase that has occurred with monotonous regularity throughout the history of man's inventions. It seems quite certain, however, that despite the forebodings of modern-day prophets, aeronautical progress will not be halted and that the future will provide spectacular developments in the field of air travel.

Although we can expect a great number of revolutionary advances in the realms of safety, reliability, comfort and economy, most of these will be based on speed.

Speed is a relatively recent phenomenon but its development has been extraordinary. Between 1920, when an automobile attained a speed of 150 mph, and 1957, when a rocket plane was piloted at 2,000 mph, top speeds were being doubled every nine years. At this rate of increase, we could conceivably attain the speed of light ( $3 \times 10^{10}$  m/sec) by the year 2124.

It seems unlikely, however, that this geometric expansion will persist much longer because, in the first place, much exploration remains to be done at to-day's speeds. Secondly, to-day's speeds already surpass anything useful on earth.

Arthur Clark has pointed out in "Profiles of the Future" that orbital speeds above 18,000 mph require considerable centripetal forces to prevent the spacecraft from spinning off into the universe. At 25,000 mph, the necessary restraining force would be very uncomfortable to the commercial passenger. Consequently, if at 18,000 mph, any point on earth can be reached from any other in 40 minutes, it seems highly improbable that people would subject themselves to heavy "g" forces to cut another fraction off a trip that could take them to the world's most distant points in well under an hour.

At a recent conference on space planning, two engineers from the Douglas Missile and Space Systems Division envisaged a re-usable, one-stage rocket ship which would fly at orbital speeds of 17,000 mph, well within a comfortable margin of "g" forces. With time allotted for launching and landing, a trip from Vancouver to Tokyo would not take more

than one-half an hour. The 114-foot tall rocket called "Pegasus" would carry up to 260 people stretched out comfortably on individual couches, on four passenger decks in the nose of the missile. The cost of developing the rocket would be up to 2 billion dollars and the cost of the first flight vehicle, about \$35 million.

In the light of present-day knowledge about heating problems at high speeds, however, we will need a lot of experience with supersonic transports before anyone flies a hypersonic aircraft or a commercial ballistic missile. But it will happen faster than you think.

In December 1967, the first prototype Concorde Supersonic Transport was rolled out of the Sud Aviation Company hangars at Toulouse, France. This aircraft, a joint French and British project, represents the greatest single advance in the entire history of commercial air travel. Capable of cruising at 1,350 mph, it will almost triple the speeds of present jet transport. It will be powered by four British Olympus turbo-jet engines, each capable of delivering 35,000 lbs. of thrust. This is double the power of to-day's jet transport engines.

Cruising at an altitude of some eleven miles up, it will whisk passengers between such cities as Montreal and London in three hours.

The Concorde is expected to fly in late summer 1968 and to be in regular service in 1971. In the next three-year period, it will be subjected to the most exhaustive ground and flight testing ever performed on an airliner.

When it enters regular service, it will be piloted by a crew of either three or four who will use automation to its maximum in order to ease their workload.

Flying in the Concorde will be as comfortable as in any jet presently in service and unless the pilot tells you, you won't know you're travelling faster than sound.

Russia is also building a supersonic transport, the TU-144. Little is known about it except the fact that its performance characteristics resemble those of the Concorde. It will carry 121 passengers at a speed of 1,550 mph and have a range of 4,000 miles.

The United States Government has been supporting a competitive study of a supersonic transport capable of flying at a speed of Mach 2.7 or almost 1,750 mph. The Boeing 2707 SST, as it is called, should fly by 1972 and be in regular service by 1975 or 1976. It will be able to trans-

port up to 350 passengers from New York to San Francisco in just a little over two hours. At 318 feet, it measures twice as long as to-day's big jets. It is so long, in fact, that the pilot will have to look at a television screen on the instrument panel to know when the main wheels are about to touch the ground.

Each of the four jet engines will produce enough thrust to power four ocean liners and the 100,000 pounds of fuel required to fly the aircraft for an hour would be enough to drive your car for 20 years.

The magnitude of the Boeing SST project can best be appreciated in terms of its cost. The bill for research and development, up to the production of the first two prototypes, is expected to total \$4 billion.

Twenty-seven airlines have already reserved delivery positions for some 130 aircraft.

The one big operational problem that exists for all three types of supersonic aircraft is the public's resistance to the so-called "sonic boom". When an airplane flies faster than sound, the air ahead of the plane cannot move out of the way in a smooth, flowing manner; consequently, shock waves are produced at the front and rear of the aircraft. When they hit the ground, they create a noise ranging in intensity from something like a rifle shot to a tremendous crack of thunder, depending on atmospheric conditions and the size and height of the aircraft.

Much has been made of this issue by the public and the press as though the engineers were plunging ahead unconcerned. However, the SST's have been designed from the beginning with the "sonic boom" very much in mind. No one suggests that the problem can be completely solved but flight patterns can be arranged so that SST's will fly at subsonic speeds over built-up areas and only break the supersonic barrier when away from centers of population. Furthermore, a considerable number of tests have been made by the Americans, French and British to determine whether or not the "sonic boom" will be tolerated by the public. In one such test performed in Oklahoma City in 1964, the U.S. Federal Aviation Agency reported that 75% of the population had found the booms "acceptable".

With respect to the SST's, much research and development definitely remains to be done. For example, better methods must be found to prevent fires and experiments are being conducted with gelled fuels and a new polyurethane foam material that will greatly reduce this hazard. Now that air

pollution is becoming a serious problem in many cities, ways must be found to reduce the smoke from supersonic jet engines without decreasing their efficiency. Although flying at high altitudes is definitely safer, weather forecasting techniques must be improved because jet streams, clear air turbulence, wind shears and heavy rain conditions can be more serious in the case of the SST.

In addition, automation must be put to work to improve the accuracy of check-out monitoring and maintenance systems, and to improve the quality and reduce the cost of training supersonic flight crews. Since it costs around \$3,000 an hour to fly an SST in crew training, a flight simulator that is more sophisticated and representative of supersonic flying conditions must be developed in order to hold actual flying time to a minimum.

However, before you fly in a supersonic transport, thousands will be flying in larger subsonic jets than anything we have yet seen.

Not only are present models being stretched to take 200 - 300 passengers, but Boeing has designed a jet with a capacity of 350 - 400 passengers which should be test flown by 1969. Known as the Boeing 747 "Jumbo Jet", it is the largest commercial aircraft ever designed. It will practically dwarf even a "stretched" DC-8. It is twice as heavy, 44 feet longer and has over 50 feet more wing. Its tail rises higher than the average five-storey building. Each of its four turbofan jet engines will produce twice as much thrust as those of the DC-8, yet it will be proportionately quieter and its 600 mph cruising speed surpasses that of present jets. The "Jumbo" will provide passengers with a level of comfort and spaciousness unmatched by present jet transports.

In the future, we will be doing a lot more flying. To-day, the world's airlines carry nearly 300 million passengers annually. By 1980, the International Civil Aviation Organization predicts a four-fold increase in this figure. Most airlines feel that the average annual increase in world air travel is between 10 and 15 per cent.

Although jumbo jets will help to reduce the number of planes in the air, there will be more than 7,000 commercial jet transports flying in 1980. Consequently, the future of air travel is to some degree dependent on how well we overcome the problems of collision avoidance and air traffic control.

Like the highways below them, domestic airways are becoming increasingly congested. At any moment during daylight hours, the Federal Aviation Agency estimates between



8,000 and 9,000 planes are aloft in the U.S. air space. Over the next decade, the FAA estimates that landings and takeoffs at American airports will triple from more than 41 million in 1966 to 139 million. Although some authorities expect the jumbos to reduce this figure by as much as 40%, the growing numbers and speeds of aircraft call for more sophisticated devices to ensure safety in the skies.

More of these devices - both in the aircraft and on the ground - are being developed each day. They go by such strange names as "ARTS", "TRACON", "DECTRA" and "OMEGA", the letters of which stand for tongue-twisting technical terms better left to the engineer.

One such system called "EROS" (Eliminate Range Zero System) already has been used successfully in high-altitude testing areas in the U.S. When an EROS-equipped aircraft is on a collision course with another aircraft, a beeping sound is produced in the pilot's earphones. Glancing at his instrument panel, the pilot sees a lighted arrow pointed either up or down in the direction that EROS calculates he should take to avoid a collision. EROS provides a 60-second advance warning at closing speeds as high as 3,000 mph, adequate for even supersonic aircraft.

Ground traffic, however, is another matter. Airfield congestion is taking on gargantuan proportions. In airline parlance, flight time is figured from the moment the engines are started until they are cut at the end of the trip. This, of course, includes the time allotted to taxiing, take-off and landing. For the two-and-a-half hour trip from London to New York, the engineers of the Boeing SST have allotted 36 minutes for these necessities. This leads one to believe that they have never spent an hour circling over London on a foggy day or waited 45 minutes to take off from Kennedy International Airport in New York!

As William Pereira, master planner for the Los Angeles Airport Commission puts it, "The real bottleneck in the jet age is not in the air but on the ground. We must break the ground barrier."

One of the most dramatic plans is that in progress in Los Angeles. Pereira's plan looks toward the construction of five new airline terminals, all underground at the west end of the airport. Among the more visionary aspects of the Pereira scheme will be lightning-like loading of jumbo jets by one of two methods. The first will be by huge, hydraulically-operated, subterranean lounges that will rise from the ground, unload their passengers via short flexible bridges, then sink quickly to the terminal below. The second will be by a system of four snorkels, equipped with escalators that will rise quickly from the underground terminal to the airplane's doors and then vanish.

At the most, however, the plan will accommodate passenger expansion for only the next eight years. It is significant that the Los Angeles airport was brand new six years ago and outmoded before the cement on its runways was dry. Thus, aircraft technology and the leap in air travel have caught even far-sighted authorities in an unexpected bind.

Despite the fact that in the last 20 years, the average airline trip has been reduced by 50%, the average trip time from city center to airport has increased by the same percentage.

Many schemes have been proposed to solve this particular aspect of the mass transportation problem. These range from comparatively conservative ideas such as the combination of high speed monorails and spurs of existing subway and rail lines to such radical proposals as hovercraft, airbuses, vertical or short takeoff and landing vehicles and pneumatic tube systems. All of these would serve to transport many more people between airports and city centers at much greater speeds than are possible to-day.

Still, authorities like Charles C. Tillinghast, the president of TWA, do not think too highly of such proposed solutions. Says Mr. Tillinghast, "The airport traffic problem is part of the general highway traffic problem." Most people prefer to go to and from the airport by car, but they have trouble getting there, and when they get there, they have trouble finding a place to park their cars. Consequently, according to our friend Pereira, long-haul and short-distance airline operations and general air traffic will have to be separated by means of new individual airports for each. The whole airport business will have to be decentralized by using "satellite" fields in the far-flung corners of the metropolitan areas. Thus, taking the airport to the people reduces the need for taking people to the airport.

The question of fares has been left to the end because most people would naturally assume that fantastic developments in air travel would make an equally fantastic dent in their pocketbook. In general, however, air fares will not change. In fact, they have been steadily reduced, world-wide, for a number of years, and one ICAO prediction shows them dropping in the next ten years, perhaps as much as 15% in terms of dollar value.

Although it is a generally accepted principle in transportation that higher speeds cost more money, civil aviation has always moved in the opposite direction. This has been possible because each increase in speed usually has been accompanied by a corresponding increase in the size of



the aircraft. As a result, the operating cost per seat-mile has been reduced, producing lower fares.

The supersonic Concorde takes a big step forward in the matter of increased speed. It will not, however, carry as many passengers as current subsonic jets. Furthermore, manufacturing, maintenance and operating costs will be higher. It seems clear, therefore, that cost per seat-mile will be as much as 50% higher and passengers will have to pay a "supersonic surcharge" to fly in the Concorde.

Because the Boeing SST is faster and carries more passengers than the Concorde, it may well produce seat-mile costs similar to those of to-day's long range subsonic jets. Thus, it appears that by 1975, people may be able to fly to Europe in two and a half hours for the same price it costs them to fly there now in six and a half hours.

Each new technology--the supersonic first, the nuclear supersonic next, the hypersonic, the commercial ballistic missile and whatever follows it--in turn will be introduced at a temporary premium. But fares on the aircraft that are then conventional will remain the same and the "dollar value" of air transportation will increase.

What value, if any, do all these new developments in air travel have to the non-travelling public? Let us consider just one benefit, although there are many. Depending on the number of Boeing SST's built, the U.S. economy will grow by 20 to 50 billion dollars and to build these new aircraft, 250,000 jobs will be created--the equivalent of all the jobs in the airline industry to-day.

In a purely practical basis, perhaps the most valid justification of man's insatiable desire for ever-increasing speed, is not to provide him with instant transportation but with instant communication. Tens of thousands of people fly regularly to be in more places in less time. They go to consult, confer, inspect, decide and lead, in a manner impossible to accomplish from a distance. They fly to see for themselves, to teach and be taught, to absorb impressions, to mix and mingle with others, to inspire and be inspired.

It is reasonable to suppose that after another 20 years of accelerated accumulation of knowledge in science and industry, it will be possible to convey specialized wisdom and critical solutions by any means other than personal contact. A time will come when meaningful communication will only be possible by direct, face-to-face encounter. It appears that the voluminous know-how which we are generating will soon get so complex that it must be shipped in the only feasible container--the human brain.

What could be the highest value of all, however, is the prospect that the conquest of speed and space may prove to be the moral equivalent of war. The absorption of energies, resources, imagination and aggression required to break the barriers of time may become an effective way of maintaining peace. Continued advances in the field of air travel can best be expressed in the words of Dr. Albert Plesman who said, "The oceans of the air shall unite all people."

SESSION CHAIRMAN  
MR. TOM DAVEY  
"WATER AND POLLUTION CONTROL"



"DEFINING THE PROBLEM FOR INDUSTRIAL WASTE  
HANDLING AT HIRAM WALKER & SONS LIMITED"

BY

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SUPERINTENDENT OF LABORATORIES  
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Historically, the developments of pollution control for all industry are related to community needs and requirements. As far as the fermentation industry is concerned, originally solids from spent grain were recovered and fed to cattle, the liquid portion going to the nearest water course. As more people used the water course, along with more industry, this discharge was considered extreme pollution, and recovery of liquid waste was almost mandatory. The recovery of this pollutant was turned into a by-product by research marketing and good engineering. Hiram Walker was cited by the Ontario Water Resources Commission for helping to fight pollution by such advanced techniques. Now, it is another era and more people are using the water courses. Newer restrictions have been and are being imposed. It has become imperative for all industries to solve their pollution problems. To do this, industry must first know what problems exist for them. Many people in and out of industry have had the feeling that when it is in the ground and carried away, particularly on a midnight shift, the solution is at hand. At Hiram

Walker, we have tried to assess our problems as completely as possible, to uncover all sources of pollution in our plant and are slowly and steadily working toward the elimination of all the problems uncovered.

After 110 years of existence, Hiram Walker has on its property 31 outfalls to the river. Of these 31 outfalls, our company uses less than half for any purpose whatsoever. A good number of these outfalls belong to the City of Windsor, and some are former water intakes which were turned into storm drains or effluent drains.

Armstrong & Associates were retained as consultants and with the help of our Engineering Department, a lot of dye and just plain work, they managed to obtain a fairly good layout of our sewers and our outfall system. It is worth noting that certain dyes such as floroscein are absorbed by some of our pollutants and will not show up in an outfall unless large amounts are used.

The next step was a task of going through the drawings and sorting out almost 100 buildings as to their use of outfalls around the property. From this, conclusions could be drawn as to which outfalls could be contaminated and should be surveyed. Some outfalls not included for survey were automatically designated as outfalls that must be totally re-routed to the city sewerage when it becomes available. There was at least one outfall included for survey which was considered to be free of pollutants. It was decided to include this outfall for survey since it contained approximately 1,200 gallons per minute of water going to the river. Seven outfalls had to be surveyed plus internal samples for segregation purposes.

All departments in the plant were contacted and a list obtained of possible sources of pollution in their area, even to the amount of soap used for washing floors, lubricants for conveyors, etc. This gave us a good working knowledge of what type of effluent to expect in particular outfalls.

We pump water from the river in addition to using city water. Therefore, sampling and flow measurements are extremely important. In this respect, we have one or two unique problems. In order to sample from the barometric leg of our evaporator and not break the vacuum, we had to use a double valved pipe system inserted in the leg. Flows from this source could be measured directly using previously installed water meters. Another problem in flow measurement is lack of proper entry to sewer lines. When a new system is built, you can incorporate your measuring devices. In our

major outfall, we first put in a weir designed for us by Armstrong based on our designated flows. It turned out, to our surprise, that instead of 5,000 GPM, we had 7,000 to 8,000 GPM going through this outfall at the time. The weir was designed to assess this much flow but the height of the river, the slope of the sewer and because of the flow going over the weir, we had sufficient back pressure to affect our getting proper estimate of flows by weir measurement. The next time we installed the weir in that particular outfall, our engineering department designed a higher weir so that we overcame the back pressure problem. We also had a new water metering system in the plant to verify flows. We came in on the weekend, opened up valves, estimated how much water went through and then checked the height over the weir by air bubbler tube. The first thing we found is that the bubble pipe was three inches too low. When this was corrected, we found curve #1 to be correct. The figures as calculated for the weir are almost identical with the flow figures as obtained by direct measurement of flow over the weir.

We built a portable device for pumping samples and taking flow measurements. We used a mud pump which does a good job of lifting almost any type of sample you might have in your sewer. The monometer which was attached to the air cylinders indicated the height above the weir very readily when a bubble tube is placed in stream. This cart could be placed at each outfall as needed. We set up a sampling program in which every sewer would be checked every hour on the hour for 14 days. Each hourly sample was proportioned according to the flow as found. These samples were pooled, and a composite sample run once a day. We ran separate B.O.D. measurements on any of the individual samples we found interesting, such as finding a very large amount of particles or anything unusual that happened such as pH change. The personnel doing the sampling were instructed to collect pint samples and measure the temperatures immediately on each sample as it went into the bottle. The pH was run on each sample when they returned to the laboratory. Alkalinity was checked on a number of these samples. However, hourly alkalinity was found to be impractical as it required too much time and uniform results for any outfall were seen with very few exceptions. These exceptions could be run on their own when found. The reason for checking pH every hour is that knowing our operations, we know there are times when a small amount of material can be discharged at a higher or lower pH than the average, as found in a particular outfall. These observations would be lost in a composite sample.

We had one other interesting problem. A milk company uses two of the outfalls with us. In order to find out what was our effluent and what was the milk company's effluent in these outfalls, we ran a survey at two different times for the

outfall, one when we were operating and then again when we were shut down for maintenance. This gave us details as to the milk company's disposal of waste in these common outfalls.

All samples were stored in a refrigerator until composited and the samples were analyzed daily as obtained. (This is a good way to be at a plant for two or three months straight).

The next problem, after choosing what to look for, is how to look for it. Methods generally found in "Standard Methods of Analyses" were the ones employed. We did have some problems using asbestos pads for suspended solids and therefore, we changed to what probably is the more common method today and that is the use of filter pads. Another difficult test and my favourite topic is B.O.D., a fairly well conceived parameter of pollution gone astray by becoming too worldly. To suggest one important problem in this area, let us consider seed. In the case of industrial effluent, everyone will agree that seeding is needed for running B.O.D. We had a problem in obtaining a reliable one. By personal observation as well as laboratory observations, the microorganisms from the river are difficult to use. Unfortunately for us, there was no place in the immediate vicinity to obtain a usable sample. Windsor did not have a disposal works when we first started our investigations. In order to obtain a proper seed, we checked some sewer lines in our area which contained domestic flow. We found that the sewer in front of our property, because of effluent from a milk company, led to the dilemma that we could not use this particular source. Table #1 indicates the data obtained using seed from this source as compared with seed obtained from the Detroit sewage disposal plant. I did have a generous offer from the people at the Detroit sewage plant. They offered, bottle for bottle, our product for theirs. Our later investigations were helped considerably by the fact that the Little River disposal plant went into operation and we were able to obtain a seed from them. We also tried the possibility of using a frozen source because of the travel needed in order to obtain a proper seed. We found that even though the literature cited cases of frozen sewage plant effluent successfully being used, it was inoperable in our hands. We found that on dextrose and glutamic acid, the B.O.D. was half of what we would expect. On a plant sample using frozen and normal seed, the same results were obtained for the sample. It appears that we had killed off some fastidious microorganisms and left others behind after freezing and thawing.

It may seem to some that I dwell overlong on this subject of proper testing of B.O.D., but when you consider what we find in the bottle has to be multiplied by many millions of pounds of water to get an estimate of our total loading to the river, you can see where 20, 30 or 40 B.O.D. can add a lot of pounds to our estimates. There is another important considera-



tion when you start to wonder about this test. The information you obtain from this consideration can give you some idea of the treatability of your wastes, if you consider your results in their proper context and not use them as merely a measure of organic pollutants.

In an effort to check on a substitute method for B.O.D., we did try to correlate C.O.D. with B.O.D. values. This might have been useful if not for the results obtained. Each particular pollutant had a different relationship to B.O.D. or C.O.D. Alcohol has a relationship of 1 alcohol to 1.3 B.O.D. and 1.7 C.O.D. This relationship cannot be applied to other materials. Therefore, it becomes imperative to have some idea of the content of the effluent before making any valued judgements as to the meaning of the relationship between C.O.D. and B.O.D. Table #2 should point this out. Note the differences between B.O.D. and C.O.D. In some cases wide differences exist and in other cases the figures are close. The C.O.D./B.O.D. relationship in the various outfalls are shown. The figures are from an OWRC report. We are happy to say we obtained essentially the same figures for these samples as they did. Outfall 23 contains material from our power house. Outfall 25 contains both power house, domestic waste, bottling waste and a milk company's waste. Outfall 29 contains our major flow area from the distillery and cereal products. Outfall 31 contains still house waste. Note the river water itself. Each outfall is different in its relationship between B.O.D. and C.O.D. It is reasonable to expect in our case, some degree of uniformity in a particular outfall but if varying types of pollutants are present, then any consistency would disappear.

Let us return to B.O.D. and some curves. This presents again a problem of assessing results. We can show that for alcohol, there is no question about the level for five day B.O.D. being equal to the twenty day results. This is not so when you take some of our materials which contain a high degree of settleable solids. The twenty day B.O.D. goes much higher than the five day figure. See curve #2.

Let us take a look at the figures for a settleable solids material sample. You will notice on table #3 that if you allow the material to settle for an hour and a half (this is related to practice in disposal systems), you will find that you have a relationship as shown. In this table we see a sample drawn purposely for this type of estimate under the worst conditions possible. The flow figures are based on a potential flow at the time of sampling. This then would estimate the potential pounds, if the PPM were constant. A base of comparison was needed so obtaining pound figures became useful. You can see that PPM means little for comparison.

After settling, by using these flow figures, based on the amount decanted, relating this to the original flow figure, pounds can in this case be extrapolated and related to one another. Using pounds as the basis of discussion makes more sense than PPM. Looking at the figures in this light, we see that approximately 25 to 30 per cent of the B.O.D. is contained in only 10% of the total flow when we look at the settled solids figures along with B.O.D. The effluent of the original sample is related to 90% of the original flow and contains only 80% of the original B.O.D.

The solids figures are logical and are related as shown in the table. This data indicates that the effluent is more treatable than the settled material as would be expected. The two together will give you a higher figure and again this is understandable based on the fact that the solids will go into solution in time. The question arises, as to what figure does one use as being the oxidizable material for assessment purposes in a disposal system? This seemingly innocent question can cause problems at times. This type of information has relevance also when running B.O.D. If you have suspended material of organic nature which can be soluble in time, will the picture change based on dilution? You can, with insufficient dilution, show a lower B.O.D. than is valid for a particular effluent.

This whole thing brings up the question of just what is B.O.D. Is it that which is found in five days, twenty days in a bottle, or that which is stabilized in a disposable plant? Are we losing sight of the original test and its origins? Are we using it completely out of context with our disposal plants and particularly when industrial effluents are to be treated? I raise these questions because they are logical questions to be asked by industry when charges are to be laid by municipalities for waste treatment or when disposal systems have to be designed.

Table #4 - let us look at some of our sources of pollution and explore what they mean. It is obvious the PPM considerations alone have little meaning. Note that the same pounds of B.O.D. are obtained with two different PPM figures. Also, that almost identical B.O.D.'s gave twice as many pounds of material when based on flow.

Looking first at the largest figure in the table-- the necessary in-plant study indicated the major flows were from unpolluted or extremely small pollution sources, cooling water as an example. The two major sources of pollution were a water curtain used for air pollution control and condensate from our evaporators. This meant that the major portion of our flow could be routed to the river and the minor flows, with high sources of B.O.D. could be routed to the new city treatment plant when it becomes operational.



will exceed solids because of alcohol sources in this outfall. This is only one of two outfalls in common with a milk company. I am presenting the complete week to indicate how we handled results from all our outfalls. We measured every day and correlated the figure as shown. You can learn a lot from looking at outfalls. The milk company cleans up on Tuesday and Thursday. They don't operate on Sunday or Wednesday. We clean up on Friday. Other high periods indicate special equipment clean up in our plant.

In the results, I tried to hold to B.O.D. figures only so as not to confuse the picture with suspended solids and total solids. In most cases suspended solids will be less than the B.O.D. figures so that as far as control of pollution goes when we contain our B.O.D., we essentially control suspended solids except as noted.

Temperature will probably not be a big factor in our treatment considerations. Table #11 shows the basis for this observation. There can be circumstances that might alter this picture but not at present. We seem easily to fall within the 150° F limits set for temperature discharge both by the city or OWRC. pH figures fall within a good range. Obviously, we have spot conditions which will need corrective action. When presented with the problem, our production and engineering personnel have taken this into consideration in future planning. See table #12 for data pertinent to this discussion.

Some of the abnormal pHs, both high and low, are caused by de-ionizer regeneration. In the almost immediate future, we will install new de-ionizing units and we plan to neutralize all the effluent from this source to maintain a proper pH for the outfall to be used by the regenerated units. Also, serious consideration is being given to some changes in operation to eliminate some of the abnormalities from cleanup of a filter in the same area. It is noteworthy that pollution control has been a consistent factor all through the various phases of planning for new equipment and facilities in our expanded plans.

Before I finish, I would like to consider one more problem. A large area of our facilities contain alcohol tanks of various sizes. In case of extreme catastrophe and subsequent discharge of a complete tank of alcohol, it would be imperative to plan in advance where this effluent should go. High proof alcohol is considered flammable; even if diluted by sprinkler water, it would constitute a large amount of alcohol going to a sewage disposal plant with some problems for the plant. In order to provide for this eventuality but still put our industrial waste into normal channels, our engineering department plans to use a leaping weir. Since floor drains have no brains or even a sixth sense, all effluent will go to the city

Table #5 indicates the findings from the air cleaner equipment. This source can be the largest single source of pollution we have. Our production people went to work on eliminating this and now it is no longer a source of pollution in our plant.

This leaves the condensate from our evaporators as the largest source of pollution we have as indicated on table #6. This can be routed to the city disposal plant along with other smaller sources of pollution as found in the plant. The next two tables indicate some of the other sources of pollution as actually tested in our laboratory.

Some of the sources of pollution shown in these tables are to be eliminated with our expansion program, such as the wet truck discharge. I assume everyone realizes that Hiram Walker is planning an expansion program which will double the capacity of our present plant by mid-1970. Some of the sources of pollution will be reduced due to changes in operation. Totally, these are small in amount and the sewers carrying them will be routed to the collection system devised by our engineering department to collect all the waste designated by laboratory findings as being necessary to be routed to the city disposal plant. The remaining flow, approximately 75-80 per cent of the total will carry little, if any, B.O.D. to the river. This discharge is planned to be carried to mid-current by a water intake we originally planned to abandon but instead will be converted to a clean water outfall. This will leave very little in the way of flow not picked up by our two-pipe system. Some flows will, of necessity, go by a more direct route to a city sewer or to the river.

We made a separate estimate of our cleanup, which is not an every day affair. These figures are not included in the previous tables. Table #9 indicates one such cleanup day. We clean up the plant over an eight to ten hour period. Few other sources of pollution are discharged when this cleanup is being done. As seen from the data, this can be a large source of pollution to the outfall. At present, our production engineering personnel are working on methods of totally recovering this material. This would eliminate one of our major sources of pollution on particular days. In addition, we must bear in mind that the observations made for previous slides would also hold for this source of pollution. The settleable solids are large and therefore, the B.O.D. picture is not as great as would appear from the figures when sent to a disposal plant.

Table #10 indicates the amount found in a common outfall with a milk company when both they and we are using this outfall and also when we used it alone. The flows are not useful alone, since storm flows are picked up in this outfall. The flows are only useful for obtaining pounds of B.O.D. and giving general flow figures. Note that in some cases, B.O.D.

until such time as a major catastrophe causes the flow to exceed a set limit. After that, total discharge will be to the river until this catastrophe is passed and true normal flow is resumed. This could mean that we have an outfall to the river we may never use, but we must plan for this event regardless.

To summarize, I have discussed some problems in evaluating pollution from our plant. In particular, I pointed out the problems in connection with evaluating sources of pollution, the amount of pollution found and how it is measured and distributed in our plant. I touched on some of our future planning using the figures obtained by these studies.

CURVE #1

# ACTUAL FLOW CURVE 36" RECT WEIR (Q)

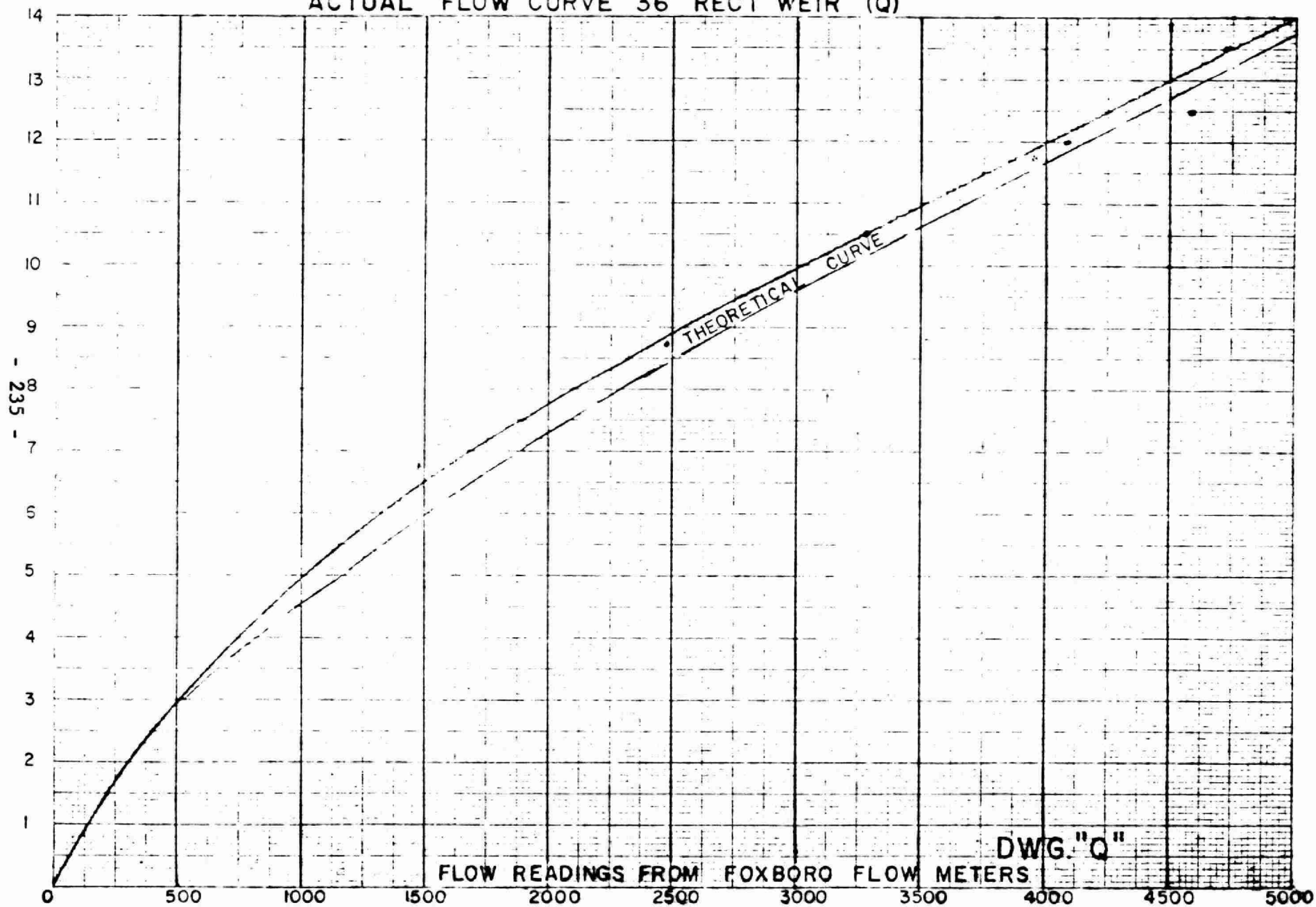


TABLE #1

SEED FROM DIFFERENT SOURCES

<u>Source</u>	<u>Amount/300 ml B.O.D. Bottle</u>	<u>B.O.D. Dextrose + Glutamic</u>
Detroit Disposal Plant	0.5 ml	192
Detroit Disposal Plant	1.0 ml	190
Domestic Sewer on Riverside Drive	0.5 ml	185
Domestic Sewer on Riverside Drive	1.0 ml	122

TABLE #2

COMPARISON OF C.O.D. WITH B.O.D.  
FOR DIFFERENT SOURCES OF POLLUTION  
VALUES FROM O.W.R.C. REPORT

<u>Outfall Number</u>	<u>PPM C.O.D.</u>	<u>PPM B.O.D.</u>	<u>Ratio C.O.D./B.O.D.</u>
23	444	41	10.8
25	172	144	1.2
29	68	60	1.1
31	552	375	1.5
River Water	25	4	6.3

CURVE #2

COMPARISON OF CURVES FOR 20 DAY B.O.D. ALCOHOL VS. SPENT GRAIN

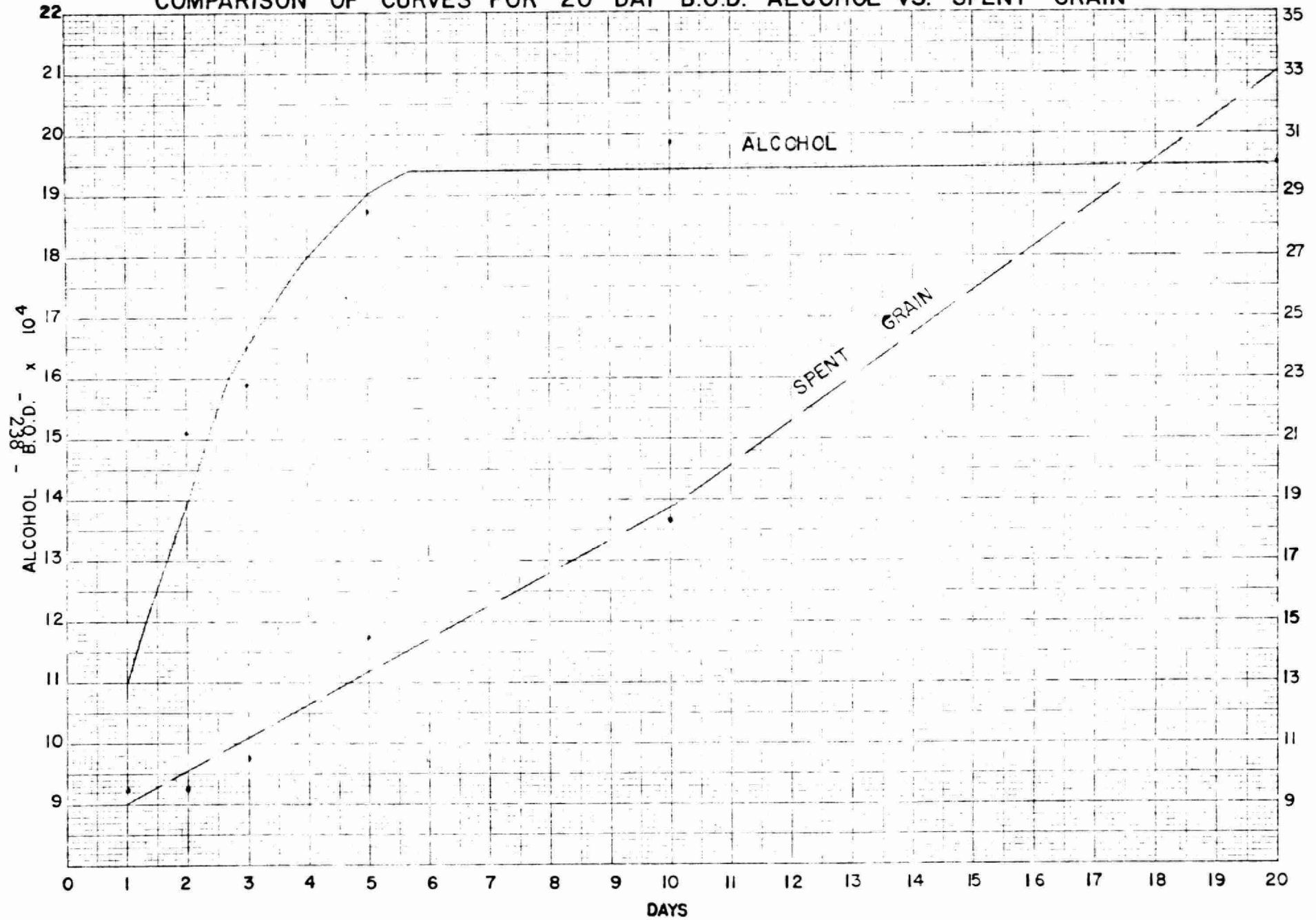




TABLE #3

EFFECT OF  $1\frac{1}{2}$  HOURS OF SETTLING TIME ON B.O.D.  
FOR SPENT GRAIN SAMPLE

	Flow Million Pounds	B.O.D.		Total Solids		Suspended Solids	
		<u>PPM</u>	<u>Pounds</u>	<u>PPM</u>	<u>Pounds</u>	<u>PPM</u>	<u>Pounds</u>
Effluent for Spent Grain	9.26	877	8,121	1,400	12,720	320	2,963
Settled Material from Spent Grain	1.54	1,975	3,041	5,730	8,824	4,550	7,007
Original Composite Sample	10.80	1,016	10,973	2,020	21,816	1,020	11,016

TABLE #4

B.O.D. IN MAJOR OUTFALLSTWO TYPICAL DAYS

	<u>Source</u>	<u>Flow</u>	<u>B.O.D.</u>	
			<u>PPM</u>	<u>Pounds</u>
1st day	Still House Area	2.26	83	187.6
1st day	Cereal Products Area	36.76	112	4,117.1
2nd day	Still House Area	5.16	94	486.2
2nd day	Still House Area	62.35	77	4,814.6

TABLE #5

FROM CEREAL PRODUCTS AIR CLEANER

<u>Hours of Flow</u>	<u>Flow M Pounds</u>	<u>B.O.D.</u>	
		<u>PPM</u>	<u>Pounds</u>
1	0.19	1,452	275.88
16	0.66	5,625	3,712.50

TABLE #6

CONDENSATE (CEREAL PRODUCTS)  
MILLION POUNDS OF FLOW AND NET B.O.D.

	<u>Flow***</u>	<u>B.O.D.</u>	
		<u>PPM</u>	<u>Pounds</u>
August 22	2.05	396	811.80
August 23	2.02	454	917.08

\*\*\* Based on estimate made from steam used in the process.

Samples from 8 a.m. to 7 a.m. of next day.

TABLE #7

B.O.D. AND FLOWS, FROM VARIOUS SOURCES OF CONTAMINATIONOUTFALL 31EAST OF DISTILLERY

	<u>Estimate of Million Pounds Per Day Flow</u>	<u>PPM B.O.D.</u>	<u>Pounds B.O.D. Per Day</u>
Ester and Aldehyde Column	.00009596	950,000	91.16
Base of Alcohol Column	.041743	121	5.05
Gin Still Clean Up	.009716	20,400	198.21
Pot Still Clean Up	.005481	2,164	11.86
Clean Up of Fermenter	.770092	356	274.15
Base of Re-run Unit	.065973	156)	9.96
Base of Fusel Oil Column		145)	
of Re-run Unit		151	

TABLE #8

SMALL SOURCES OF CONTAMINATION IN THE DISTILLERY AREAMILLION POUNDS FLOW AND NET B.O.D.

<u>Source</u>	<u>Million Pounds Flow Per Item Shown</u>	<u>Pounds B.O.D.</u>
Yeast Tub	.048	.63
Cleanup of Yeast Lines	.027	.46
Wet Grain - Truck Leaking	.002	36.69
Pressure Cans - #16	.000027	.349
- #6	.00053	15.32

TABLE #9

TYPICAL DATA FOR DISTILLERY CLEAN UPAUGUST 12, 19668:05 A.M. UNTIL 3:55 P.M.

<u>Sample</u>	<u>Flow</u> <u>Million Pounds</u>	<u>B.O.D.</u>	
		<u>PPM</u>	<u>Pounds</u>
Manhole #17 - Outfall 29	5.69	311	1,769.59
Assumed for Distillery	11.05	594	6,566.93
Composite for Manhole #18 - Outfall 29	16.74	498	8,336.52



TABLE #10

OUTFALL #13MILLION POUNDS FLOW AND NET B.O.D.JUNE FIGURES INCLUDE MILK COMPANY AND HIRAM WALKERJULY FIGURES DO NOT INVOLVE HIRAM WALKER

<u>Date and Day</u>		<u>Flow</u> <u>Million Pounds</u>	<u>B.O.D.</u> <u>PPM</u>	<u>Pounds</u>
June 12-13	Sunday	0.06	5	0.30
13-14	Monday	0.07	267	18.69
28-29	Tuesday	0.19	469	89.11
29-30	Wednesday	0.47	200	94.00
9-10	Thursday	0.20	297	59.40
10-11	Friday	0.17	676	114.92
11-12	Saturday	0.09	124	11.16
Total per Week		1.42	273	387.58
July 10-11	Sunday	0.04	44	1.76
11-12	Monday	0.08	38	3.04
12-13	Tuesday	1.01	35	35.35
13-14	Wednesday	0.37	4	1.48
14-15	Thursday	0.34	88	29.92
15-16	Friday	0.27	45	12.15
16-17	Saturday	0.25	38	9.50
Total per Week		2.36	39	92.20

TABLE #11

COMPOSITE TEMPERATURE OF ALL OUTFALLS  
FOR HIGHEST TEMPERATURE DISCHARGE DAY

	<u>Temperature</u>	<u>High*</u>	<u>Low</u>
Treatable Flows	104	190	85
Clean Water	82	**	
Total Water	83		
River Water	70		

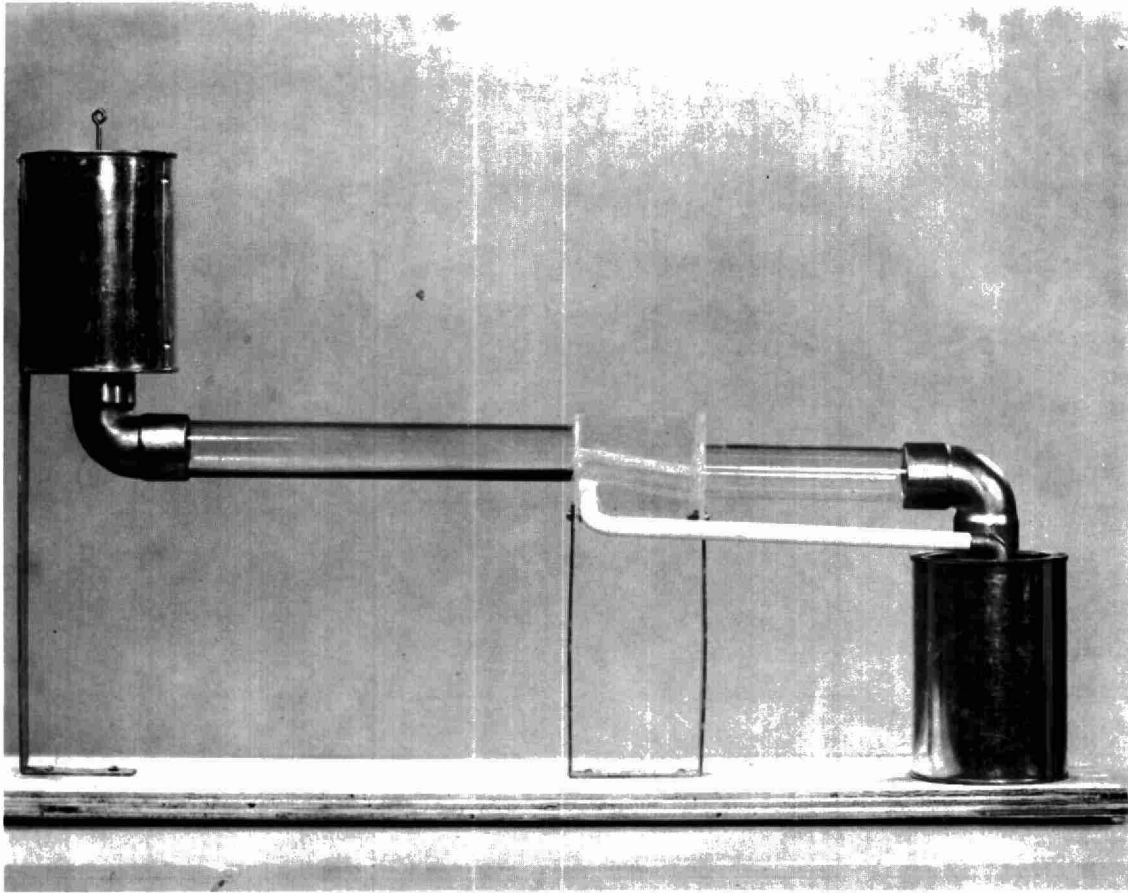
\* One Source Only of Low Flow Material but not Directly into River.

\*\* No Estimate Possible.

TABLE #12

PH OF OUTFALLS FOR WEEKS OF SURVEY

<u>Outfall Number</u>	<u>High</u>	<u>Average</u>	<u>Low</u>
13	11.00	8.70	6.70
23	9.30	8.45	6.40
25	11.00	7.90	2.10
26	11.30	7.95	5.50
28	8.20	7.95	7.35
29	11.10	7.40	5.40
31	10.45	8.20	6.35





"BIOLOGICAL ASPECTS OF WATER QUALITY  
MANAGEMENT IN ONTARIO"

BY

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In May of 1967, a series of policy guidelines were approved by the Ontario Water Resources Commission which heralded a broadened philosophy on the part of this agency toward its basic responsibilities of water supply and pollution control. These policy guidelines established the foundation for a total watershed approach in the application of water management policies and goals, based on recognized beneficial uses of water throughout any drainage system. The need to develop sound and clearly defined expressions of beneficial use was recognized, as was the desirability of a suitable democratization of the process of watershed planning which would clarify rightful interests of various water users.

The policy guidelines provided for the establishment of minimum quality control objectives for general application throughout the Province, in order to maintain and upgrade existing water quality in the face of burgeoning industrial and municipal growth and rapid technological change. Provision has been made for the implementation of more stringent objectives than those adopted for general application where specific beneficial uses necessitate this action.

The next step in this evolving program will be the development and adoption of water quality criteria. These criteria will be flexible numerical or descriptive limits for specific waste components which will clearly define the requirements for each major beneficial use, including domestic water supply, recreation and aesthetics, fish and wildlife propagation, agriculture (irrigation and livestock watering requirements) and industrial water supplies. These criteria will, in turn, determine the wastewater effluent controls that will be imposed on industries and municipalities in order to achieve the objectives for water quality which are adopted within any watershed management plan.

The purpose of this presentation is to indicate the present and anticipated contribution of the biologist in pollution evaluation and in shaping watershed management plans and policies. Within the Commission, an integrated multi-discipline approach to pollution evaluation and control has materialized. This year, a major survey (on the Ottawa River) is in progress which has field-based engineers, chemists, bacteriologists and biologists working together on the definition and quantitation of waste inputs, concentrations of pollutants in the river, the fate of waste components, the inherent capacity of the river for self-purification, and the effects of pollution on beneficial uses.

### Water Quality Surveys

Priorities for water quality evaluations are usually established through mutual consultations between survey biologists and engineers having responsibilities in the field of industrial waste control and water quality forecasting and analysis. The nature of any water quality survey varies with the magnitude and complexity of the problems existent and the size of the stream, river or watershed receiving attention. In some cases, a limited survey may be undertaken independently by engineers below a specific source of pollution to establish the assimilation capacity of the receiving water for degradable organic wastes and the related limitations on waste loadings and rates of discharge that must be applied to protect the recognized beneficial uses. In other cases biologists undertake independent surveys to evaluate the relationship between nutrient discharges and the production of troublesome algae or to establish a connection between malodorous wastes and the tainting of fish flesh. In large-scale watershed surveys, having a planning orientation, a thoroughly integrated approach is fostered to obtain results

that are obtained without unnecessary duplication of effort and which reflect the flexibility that is provided by accomplishing the biological program in the light of physical, chemical and engineering data and vice versa.

In many cases, co-operative efforts are established with other government agencies to obtain information essential to a thorough understanding of a specific water resource or to obtain assistance in accomplishing a particular goal within the framework of the broader survey. Fish and wildlife personnel of the Department of Lands and Forests contribute information on fish populations and angler-exploitation and provide fish for flavour evaluations and pesticide analyses. During one survey in 1967, arrangements were made through the Department of Agriculture for the enlistment of 4-H Club members to collect samples from run-off streams as a contribution to establishing a nutrient budget for the watershed. Permanent arrangements for the collection and submission of water samples to permit regular monitoring of stream conditions have been established between the Water Quality Surveys Branch of the Commission and the Conservation Authorities Branch of the Department of Energy and Resources Management. Samples are now collected regularly for this purpose at approximately 500 locations throughout the province.

#### Biological Assessment of Water Quality

Biological evaluations of water quality may include one or more of the following: studies of the effects of pollution on the species composition and productivity of aquatic communities, field and laboratory fish toxicity and bioassay studies to determine the toxic properties of waste discharges, flavour evaluations where tainting of fish flesh is a potential hazard and, for the first time this year, a method for determining the 'algae growth potential' of waters under study.

Biological surveys may be of one of four types. Spot surveys are undertaken, usually with some urgency, to evaluate the effects of pollution in a specific local situation in order to promote effective remedial action. Watershed surveys are performed to evaluate the over all condition of entire watersheds and to assess the impact of each specific source of pollution on the watershed as a whole. The priorities for surveys of this type are established through consultation with engineering staff who are responsible for municipal and industrial waste assessment and control and the survey may involve direct co-operation with staff completing waste assimilation studies. These watershed surveys are basic to the establishment of watershed management plans and the applicability of specific beneficial uses is clarified as this type of survey

progresses. Surveillance surveys are undertaken periodically to monitor conditions at selected key stations along watersheds, based on comparisons with baseline data accumulated during watershed surveys. Information acquired during surveillance surveys serves to clarify the significance of new sources of pollution or modifications in existing treatment processes. The fourth type, special surveys, are undertaken to increase the value of the former three. They include descriptions of the primitive norm (i.e. assessments of unpolluted waters for purposes of comparison), studies of the composition of aquatic communities where an unusual type of pollution exists or where a complex combination of natural and artificial factors is present, and finally, studies to improve confidence in sampling techniques and sampling intensity or the manner of processing and identifying sample material. Very often, special studies of these kinds are developed within the framework of spot or watershed surveys.

#### Aquatic Communities

The term biological survey as applied in its most limited sense, relates to an evaluation of plant and animal communities in relation to known and suspected sources of pollution. Prior to the adoption of specific techniques for undertaking biological assessments of water quality, a thorough review was made of the historical development of the methodology and interpretative aspects of water quality evaluation, as well as current trends. Thus, in the shaping of our procedures, cognizance has been taken of the significant contributions made by such well-known workers as Bartsch (1), Beck (3, 4, 5), Doudoroff (6, 7), Gaufin (8), Gaufin and Tarzwell (9, 10, 11), Hynes (12), Ingram (13), Palmer (15, 16), Patrick (17, 18), Smith (19, 20), Tarzwell (21) and many others. As a result of this review, techniques were adopted which placed emphasis on the study of the plant and animal community as a whole, rather than the use of specific indicator organisms which was popular several decades ago.

Undoubtedly, the greatest value of the biological survey lies in its potential to reveal the effect of past adverse environmental conditions, even of brief duration, on aquatic communities. Spot sampling for chemical analyses may or may not be revealing, depending on the operational vagaries of the industry or sewage treatment plant concerned, whereas the aquatic community serves to reflect variations in water quality over extended periods.

While it is not intended to present lengthy detail on sampling procedures or the interpretation and presentation of biological data, a few major points are noteworthy.



Sampling is undertaken above and below a source of pollution and sampling sites are selected which are ecologically similar, including such features as flow characteristics and bottom types. An effort is made to sample each of the different environments presented by any river or lake situation e.g. riffles and deep pools or littoral and profundal areas. Whenever possible, quantitative and qualitative data are obtained on bottom fauna, benthic algae, plankton and fish. Each site is sampled a number of times to increase the reliability of results. In some cases, sampling is carried out in the spring or early summer as well as late summer, especially where drought conditions produce periods of extremely low flows or where industries such as canneries which operate on a seasonal basis are located.

Biological interpretations are usually based on the composition of the total macroinvertebrate population and the presence and relative abundance of 'clean water' and 'pollution-tolerant' forms, as well as the diversity and relative abundance of fish species. Clean waters are usually characterized by a wide diversity of species with no marked numerical predominance of any one type. On the other hand, 'the community in organically polluted waters is composed of large numbers of a reduced number of species, the survivors being scavengers adapted to living at reduced oxygen tensions' (Johnston, 14). Toxic pollution may have an entirely inhibitory effect on the localized production of aquatic life, and the diminishing effect with time and distance is usually obvious from the results of the survey. However, because of the complexity of waste discharges from modern industries, it is most difficult to establish cause and effect relationships between specific pollutants and their effects on community dynamics. Knowledge of the habits of specific organisms, their life histories and the influence of natural factors in affecting the distribution and numbers of invertebrates, plankton and fish is essential to make valid interpretations of biological data.

Difficulties are experienced in the preparation and presentation of biological survey reports owing to the multiple purposes they are designed to serve. On the one hand, there is the need to produce reports that provide a meaningful assessment of pollution for other water resource managers with little or no biological training, as well as for municipal officials, industrialists and various public organizations. On the other hand, technically detailed information must be documented to permit ready comparisons with the results of future investigations or water quality. Two separate reports are sometimes required to accomplish these goals. In the more popular reports, explanations of the interpretative rationale must be presented in simple and

concise terms. To assist the uninitiated, data are often summarized and presented graphically by means of histograms and sector diagrams to clarify the relationship between relative numbers of pollution-tolerant and intolerant groups or individuals at different stations. Occasionally, coefficients of similarities are presented which take into account the frequency of occurrence and numerical density of each taxonomic group and which permit comparisons of the occurrence of similar and dissimilar species at different stations. The 'biotic index' established by Beak (2) is another useful means of analysis and presentation of data that has been utilized. The 'index' indicates the degree of pollution by allotting a score to the bottom fauna collections, based on the relative numbers of pollution-tolerant, facultative and pollution-sensitive macro-invertebrates present. In all surveys, the necessity of providing data that will meet the requirements of statistical analysis and presentation is recognized and strived for and during 1967 and the current year this has led to fewer but more detailed surveys.

Studies of aquatic communities are always considered in the light of physical and chemical data which are obtained either during general water quality surveys or are collected as an integral part of the biological survey. Of particular importance for their interpretative value in assessing organic pollution are data on dissolved oxygen levels, biochemical oxygen demand, suspended and dissolved solids and nutrients such as nitrates and phosphates. For toxic pollutants, an understanding of the industrial process is essential in order to provide guidance to the industrial waste laboratory as to the analyses required.

#### Toxicity and Bioassay Studies

Where fisheries production and harvest is the most significant beneficial use, studies on toxic effects assume paramount importance. To Commission biologists, fish are of interest as an end in themselves, as well as providing a means of interpreting water quality, and the same may be applied to aquatic invertebrates which are important as fish food organisms. Several surveys are being conducted this year in which caged invertebrates and fish are being retained below industrial waste outfalls to determine toxic effects. Standardized static bioassay tests to establish median tolerance limits for fish are completed at the laboratory on receiving waters and industrial waste components. These tests provide an estimation of the degree of treatment or dilution required to safeguard fish populations. Stringent controls are especially essential for particularly toxic substances such as zinc, copper, lead,

chromium, cyanide, arsenic and pesticidal compounds. Construction has now commenced on our first constant flow and proportional dosing unit, which will permit a range of concentrations to be applied to fish in exposure chambers where there is a constant introduction and removal of the test solution. This technique is essential for volatile or unstable compounds and for extremely toxic substances tested at low concentrations, since the quantity removed by the test organism may be a high proportion of that contained in the test water. Also, possible interference from excretory and other waste materials from the test organism is eliminated in flow-through bioassays. Finally, constant removal facilities permit studies of sub-lethal effects over long-term periods.

### Fish Flavour Evaluations

The presence of foreign flavour in fish has been related to specific industrial waste discharges by means of panel tests to determine the presence of taint in fish samples. Standardized procedures have been developed for this technique, in which a panel of six or more persons participate in a 'tasting session' to compare the quality of 'suspect' fish with control samples of the same species. Small sections of fish are baked and, identified only by number, are presented to the participants who record the presence or absence of foreign flavour and rate its intensity. Usually, threshold odour determinations are completed on water samples obtained above and below a source of pollution to supplement the data obtained from the taste tests. Participants on taste panels have demonstrated a consistent capacity to identify tainted fish and in some cases the results have even yielded a relationship between the intensity of foreign flavour and distance from an industrial outfall.

### Aquatic Enrichment and Algae Growth Potential

Evaluations of the effects of nutrient inputs from agricultural and urban run-off, sewage treatment discharges and industrial inputs include qualitative and quantitative studies of standing crops of phytoplankton, chlorophyll analyses and, for the first time this year, an attempt to assess algae growth potential. The latter technique involves a comparison of the productive capacity of filtered water samples inoculated with algae under bacteria-free laboratory conditions with growth curves established for ideally-maintained algal cultures. It is hoped that this will provide a practical means of rating the productivity potential of lakes and rivers and may serve to demonstrate the enriching influence of specific waste discharges.

## Future Considerations

The adoption of watershed planning policies and programs and the selection of water quality criteria related to specific beneficial uses will place an increasing responsibility on the biologist. It will be essential to provide more refined information on the relationships between specific pollutants and effects on the biota and related use considerations. This will be extremely difficult for complex wastes such as those from pulp and paper mills and many chemical industries which both exert an oxygen demand and are potentially toxic. The difficulty is compounded by mixtures of substances of unknown toxicity, the characteristics of which may change from day to day owing to varying processes, raw materials and rates of production and variations in the end product being manufactured. There is an immediate need for mobile bioassay units equipped with constant flow apparatus to define waste treatment requirements by the acquisition of data on-stream, which will eliminate much of the guess-work associated with current laboratory procedures. Such facilities will permit the testing of various wastes from an industry without delays associated with handling and transport and will permit the preparation of test solutions using water obtained from the river or watercourse receiving the discharge. The biologist will have to be awake to the possibility of biological magnification for pesticides and other stable substances owing to food chain relationships, the occasional development of synergistic effects and the many interactions between multiple contaminants and numerous environmental variables.

The problem of the artificial enrichment of our waters resulting from the addition of nutrient materials must be kept under close scrutiny. A phytoplankton inventory program has been established by the Commission to gain information on increases in phytoplankton numbers in selected waters and to detect shifts in the dominance of phytoplankton species. Such information will have to be correlated with data on nutrient concentrations and other physical and chemical parameters which are indicative of increasing eutrophication. Only by accumulating factual information on potential problem areas will it be possible to stimulate the need for the development and implementation of expensive nutrient control facilities and practices.

To make possible the essential integration of large quantities of physical, chemical and biological data, the biologist must make the most of electronic data processing, notwithstanding the logistical problems presented by the unlimited diversity of the flora and fauna, the unwieldy taxonomic nomenclature and the dynamic nature of his inexact science.

It is the responsibility of the ecologist to demonstrate and emphasize the need for compliance with natural laws and the dangers that are inherent in unchecked environmental modification. If we are to ensure the future of man himself, as well as the preservation of life forms which are valued highly and will be valued more highly with increased prosperity and leisure time, we must begin to exercise a more solicitous concern for our environment, which is a closed system having definite limits for waste disposal. The combined potential effects of the degradation of our water resources by pesticides, radionuclides and thermal pollution, superimposed on the more conventional industrial and municipal waste problems, cause one to wonder whether man has outstripped his capabilities for maintaining control of the situation. Certainly, Ontario is not without its problems. Eight biological surveys of major watersheds completed so far in Northern Ontario have provided clear evidence of serious impairment of water quality, mostly from mining and pulp and paper mill wastes. It would appear that slow progress in rectifying these problems may be due in part to the philosophy expounded by Roy F. Weston who, in pointing out that pollution abatement reduces profits and can even cause serious economic problems for industries, said that "the industrial manager is obliged to abate pollution at minimum cost and to delay such costs as long as possible"(22). It is obvious that a more imaginative philosophy and concerted action are imperative when one considers the magnitude of our existing problems and our present rate of industrial growth. Whether this philosophy will be founded on an economic base of reduced profits, tax concessions, higher consumer prices, increased production efficiency or a combination of several or all such measures, we must quickly embrace Stewart S. Udall's contention that, "The time has come for us to evolve an ecology of man in harmony with the constantly unfolding ecologies of other living things". Udall goes on to say that "...We have learned neither how to grow, nor at what pace, and that is our failing and our future trouble". (23).

If I am concluding this address on a philosophical note, it is because I feel that the greatest contribution of the biologist is and will be to preach the gospel of the ecological approach to human progress. Our society must forsake its preoccupation with production statistics, annual incomes and all the revered gadgets and pleasures of twentieth century living long enough to question our present values in the light of future possibilities with respect to environmental relationships, including those between man and his fellow man, as well as between man and his physical environment. The stakes for mankind are high - certainly human betterment and, at worst, self-preservation.



### Acknowledgements

Much of the rationale and methodology of the current biological surveys program of the OWRC reflects the impetus provided by M. G. Johnson at the commencement of surveys work in 1964, as described in his founding report "Scope and Organization of the Biological Survey Program".

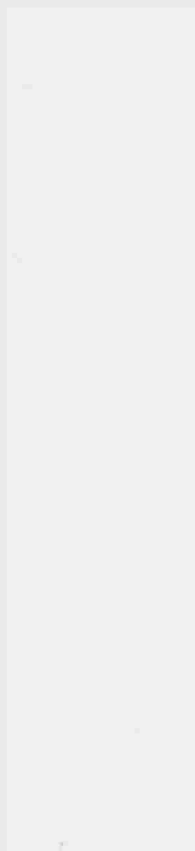
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